Range Research Methods

A Symposium
Denver, Colorado
May 1962

Miscellaneous Publication No. 940

U.S. Department of Agriculture • Forest Service

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A Symposium • Denver, Colorado • May 1962

Sponsored by the Division of Range and Wildlife Habitat Research, Forest Service

MISCELLANEOUS PUBLICATION NO. 940

U.S. DEPARTMENT OF AGRICULTURE

DECEMBER 1963

FOREST SERVICE

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Foreword

Range research furnishes the scientific basis for intelligent management of rangelands used for grazing. It is an American innovation arising primarily in response to the needs of public land administrators for knowledge on which to base sound management. It evolved from the early observations of explorers, military leaders, and missionaries of native vegetation and from the explorations and investigations of both Federal and State agencies in the late 1800's and early 1900's.* These efforts, although primarily concerned with botanical work, did recognize grazing problems and the need for research. Range management research has since expanded considerably and is now an important part of the program of the Forest Service and Agricultural Research Service, both of the U.S. Department of Agriculture, as well as many State Agricultural Experiment Stations.

Range management research in the Forest Service originated more than 50 years ago in the studies of James T. Jardine and Arthur W. Sampson on the Wallowa National Forest in Oregon. Since the initial studies of these range research pioneers, the program has steadily grown. Today some 75 scientists through the United States are working in range and wildlife habitat research.

From time to time Forest Service range researchers have met to consider mutual problems and exchange ideas. The first servicewide conference was held in July 1939 at the Great Basin Branch of the Intermountain Forest and Range Experiment Station. It was concerned with such matters as the research program, problem analysis, planning studies, conducting experiments, and making research results available to the users. The second conference, held in 1949 at Ogden, Utah, was aimed primarily at defining regional objectives. Emphasis was placed on range seeding and noxious plant control research. Particular note was made of the wide regional variations in vegetation, soils, climate, and fauna, and the need for research to encompass these many different conditions.

Over the years much has been learned about the various range plant communities and the interrelations of their many components. Applied research, sometimes guided by fundamental studies and sometimes merely by trial and error or even intuition, has produced suitable management practices for a number of range areas. However, progress has been impeded by the difficulties of measuring soil and plant attributes of the range community and the effect of grazing, fire, logging, weather, and other factors on these attributes.

Most measurement methods are too time consuming for either research or administrative use. Recently, much progress has been made in the electronic processing of data and in the development of instruments such as the neutron probe for determination of soil moisture. Similarly, better equipment and methodology can be developed for rapid and accurate measurement of both biotic and physical characteristics of the range ecosystem. For these reasons emphasis in this third servicewide conference was placed on range research methods—an evaluation of the status quo and possibilities for improvement. In addition to an introductory discussion of why range research is conducted and some of the associated difficulties, four major subject areas were considered: Vegetation measurement and sampling, site evaluation, measurement of range utilization, and the design and conduct of grazing experiments.

In order to assure coverage of the selected subjects, assignments were made about a year in advance of the meeting, and the participants were instructed to critically evaluate past work and if possible propose new ideas or improved ways of doing specific jobs. Following the individual presentations, the entire group participated in a discussion of the subject under consideration. The highlights of these discussions are included in the committee reports for each section of the symposium. In addition, certain recommendations were made by the various committees. Except for editing, the individual papers and the committee reports are essentially as presented at the Conference. The material reported herein, then, represents the views of the individuals and the committees directly concerned and not necessarily those of the Forest Service.

James P. Blaisdell,
General Chairman

Kenneth W. Parker, *Director*
Division of Range and
Wildlife Habitat Research

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*For a full account see "The History of Western Range Research" prepared by the Division of Range Research, Forest Service, United States Department of Agriculture. Agricultural History 18: 127–143. 1944.

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Contents

Introductory Session

WHY RANGE RESEARCH—AND HOW

Robert S. Campbell

This introductory paper summarizes the objectives of Range Management and Wildlife Habitat Research in the U.S. Forest Service, touches briefly on the complex and dynamic nature of the range resource, emphasizes the research problem rather than the experimental technique, illustrates research approaches to a series of broad range management problems, and concludes with the suggestion that range scientists develop an increasing sense of husbandry and perception.

RESEARCH OBJECTIVES AND POLICIES

Range Management and Wildlife Habitat Research, as pointed out in the Forest Service Manual (Sec. 4203), "seeks to develop knowledge for improving or maintaining and efficiently utilizing forage and wildlife habitat values . . . of forest and related rangelands, consistent with production of timber and water and with the conservation of the basic resources of these lands." It includes both basic research in a quest for scientific principles, and applied research in applying known principles and procedures to new or different conditions.

The policies governing Forest Service research recognize the dynamic nature of the forest and range resource. They indicate the need for a continuing program sufficiently stable to measure changing conditions, yet flexible enough to meet changing needs. Equally important, they require planned research on specific problems.

RESEARCH PROGRAM FOR A DYNAMIC RESOURCE

Forest Service range research is carried out by 10 forest and range experiment stations, the Washington Office, and hundreds of private, State, and Federal cooperators. The 30 or more vegetation types under study vary from the northeastern hardwoods to the California annual plant ranges, with great differences in climate, physiography, soils, and kind and degree of animal pressure. But through the individual research projects of the national program runs a common theme of rehabilitation, ecology, and management. In brief, the aim is to delve into the ecology of each of these many range types, i.e., into the relationships of the plants and animals to themselves and to each other in their total environment, including man.

This research must continue indefinitely because it deals with ever mutable conditions. Every square inch of land is dynamic, changing from moment to moment. The researcher, through keen perception and judicious sampling, can catch a few glimpses of the panorama, even though one man's lifetime is but a fleeting moment in the half-million years or so that mankind has been on Earth. The scientist can gain some understanding of the physical makeup of one range at a particular time, take repeat observations to record changes, and then evaluate the factors at work. If he determines principles of ecological cause and effect rather than facts alone, his results should find wide application.

Information on the identity, occurrence, and distribution of plants and animals in the major forest and range types is available in scientific books and periodicals. Grazing seasons and use of these types by domestic livestock and big game animals are generally documented. Something is known about range plant growth and reproduction, the influence of soils, physiography, and weather, and the response of plants and animals to various seasons and intensities of grazing. But with continually increasing pressures on the land for grazing and other uses, there is need to know not only what is happening, but to analyze how and why. Such analysis is prerequisite to the synthesis of findings into conclusions and recommendations for new or improved management of animals, vegetation, and soils. For example, range scientists still do not know all the important reasons for progressively lower productivity during the past 60 years on many areas with low rainfall, or how to reverse the trend even with drastic artificial treatments.

Changing times bring new problems. To illustrate: Are present beliefs and findings on grazing season and capacity well adapted to the best use of other resources in developing multiple use?

PROBLEMS VERSUS METHODS

These Proceedings go into great detail in methodology: clipping versus estimating herbage yields; measuring plant area, height, density, distribution, and botanical composition; evaluating soil fertility, texture, structure, bulk density, pore space, and moisture; and estimating utilization. However, a technique is just that, and no more. It becomes merely an exercise unless it is employed on a definite problem.

Problems are of several grades. First, there is the broad problem of wide scope in subject matter or territory. Next, there are refined phases susceptible of solution by research. And, finally, there is the small segment or group of variables selected for survey or experiment in the individual study. The scientist must continually ask: (1) What is the problem? (2) What is to be measured? (3) How can it be measured most accurately and economically? Each new problem or study should be approached with an impartial viewpoint in selecting the experimental variables and in determining appropriate measurement techniques.

BROAD METHODOLOGY

The broad approach to methodology—defining the specific problem and deciding what to measure and how to measure it—can best be illustrated under each of the major topics: Vegetation, Sites, Utilization.

Vegetation.—Visualize a cattle range where the plant species, grazing preferences, herbage production, and reasonable seasons and stocking rates are known or can be estimated. To establish specific grazing-capacity recommendations in this type, information is still needed on the year-to-year variation in production as influenced by moisture, temperature, and perhaps light. Should this problem be approached on small plots or on large range units, and what vegetation measurements will be needed?

For discussion's sake, suppose the first study is set up with small plots for direct determinations of herbage weight. Assume that these plots are in temporary exclosures moved each year to avoid cumulative divergence from grazed conditions. Then there are such questions as which species to measure, clipping vs. estimating, time and frequency of measurement, height of stubble, precipitation, soil moisture, size and number of plots, and replications in location and time. Answers depend on field conditions, manpower, facilities, and availability of research-planning factors.

Several years of work on small plots no doubt establish the relative extent of variation in forage production and explain some of it. The next questions are "Do the results provide the base for determining grazing capacity in this type? Or should the small-plot study be extended to other parts of the range to include the effects of different soils, precipitation patterns, etc.?"

A second broad problem of vegetation measurement might be approached in a very different manner. A dominant palatable species appears to be declining and a shrubby pest spreading—certainly a very common occurrence. Here, one of the first needs is a study of ecological life histories of both species and perhaps of other companion species as well, starting with measurements of seasonal growth, development, and reproduction of individual plants (Stevens and Rock 1952).[1] The results will suggest followup research. Is there need for a study of modified management practices aimed at meeting the "shrub invasion," or for experiments with shrub control methods, or both? Either study would require appropriate measurements of changes in plant composition or dominance in response to grazing or shrub-control treatments.

A third problem in vegetation measurement on our hypothetical range might occur if the range were an important watershed on which the need to minimize erosion made it seem necessary to increase and maintain the plant cover. Here, the amount and distribution of protective cover might be determined on transects.

Under the heading of vegetation measurements, three very different problems have been illustrated, each with a different approach: Herbage weight on plots, ecological life history of individual plants, and composition or cover on transects. This inevitably leads back to the point that when the problem is clearly stated and a specific objective is formulated for a study, the broad approach and methodology tend to fall into line.

Sites.—Site is defined by the Society of American Foresters (1958) as the entire environment, but it is frequently dealt with mainly in terms of soil factors. Therefore, consideration of site may well be illustrated with soils as an example.

What range problems require measurement of soil factors, and what soil characters can be measured? The standard soil classification, set up originally for agricultural purposes, has very limited usefulness in range research and management. It is based on little quantitative data, is often applied subjectively, and is highly variable. In fact, for certain characteristics there is as much variation within as between series of a textural type.[2]

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[1] Names and dates in parentheses refer to Literature Cited, p. 155.

[2] Andrews, L. E. and Stearns, F. W. Physical characteristics of four loessial soils in Mississippi. U.S. Forest Serv. South. Forest Expt. Sta. [Unpublished.]

Now to continue with the example of the range mentioned previously. Visible soil differences appear to be important in the botanical composition and productivity of plants on different parts of the range. Are such differences associated with measurable soil factors, and is there need to calculate the correlations? If so, how does the range scientist approach the problem? An understanding of these relationships may lead to significant modifications in range and livestock management, particularly in grazing season and intensity, for different plant types or units.

A good place to start is with an evaluation of different soils as sources of water for forage plants. One measurable factor is available water capacity in the plant root zone or zones. Another is depth to and thickness of moisture-inhibiting layers. Factors of the soil moisture regime may prove significant—moisture depletion and recharge rates, for example, or patterns of periods (days) below wilting point during the growing season. Aeration as measured by amount of big pores may be important. The large variation in and the labor of sampling have impeded intensive study of range soil factors, but it is a job the range researcher must find the skill and time to handle. No doubt shortcuts can be developed for measuring soil attributes. For example, Broadfoot and Burke (1958) suggested estimating available soil water from percent of silt.

In any case, the range scientist can select the pattern and techniques for sampling vegetation or forage production as the dependent variable, add pertinent measurable soil attributes as independent variables, and work out appropriate multiple regressions for solution on electronic data processing machines. Major (1951) has suggested one quantitative approach to this problem of site productivity, and Morris (1960) has abstracted literature on the whole field of statistical methods in range and related pasture research.

Utilization.—Herbage that is gone can't be measured, but it can be estimated from other attributes that can be measured. An entire section of these Proceedings is devoted to this topic. But what range problems require such measurements?

An example is determination of the optimum utilization under which valuable forage plants survive, grow, and reproduce. This is an important part of the even greater problem of range condition and trend.

Where does the researcher start? He might first establish the forage production potential under grazing use of the sample range mentioned previously. Over a period of years, he would apply experimental grazing treatments that are light, about "proper," and so heavy as to result in deterioration. This study may permit him to recommend grazing capacity and stocking rates.

Complete working knowledge of range condition and trend will necessitate studies of herbage production by major forage species, by seasons. It will require a knowledge of plant succession in order to take advantage of natural vegetation trends. Alert range research and management must recognize opportunities to maintain optimum grazing by supplementing normal range productivity with such practices as seeding or fertilizing. On the other hand, there may be occasions when the succession should be held back by selective plant control, burning, grazing, or other means.

The phases of this problem are too numerous to be studied simultaneously by the scientific manpower and facilities any one station is likely to have soon. So it must be approached piecemeal. All the studies previously mentioned contribute to the ultimate solution. The work will require small plots, large plots, laboratories, greenhouses, and grazed ranges. It may also indicate entirely new approaches—the result of observation and reasoning that every good scientist must find time to do. What factors best express range condition and trend, and which are most readily evident or measured? Also, does the study of energy dynamics offer an ecological method that would give range men improved understanding of the entire land resource and clues to its improved management?

HUSBANDRY AND PERCEPTION

The foregoing examples are intended more to stimulate thought and discussion than to provide answers. This paper might have taken up such specific questions as the best measure of dominance or the equivalence of various measures. These are excellent questions, but the answers may vary by range type and location.

There is the topic of objectivity vs. subjectivity in choosing research problems, in doing research, and in drawing conclusions from experimental results. On this subject also there is no final answer, but good judgment based on logic must supersede personal opinion or prejudice. One famous biologist claims that "the great creations and the great comprehensions, where the monumentally obvious is seen for the first time, are always the products or experiences of individual minds operating alone, free from the distractions of other human voices" (Berrill 1955). Such contemplation encourages two mental attitudes, husbandry and perception, which can help improve human judgment. Both are vital to range managers and researchers. Both are characterized as the higher grades of outdoor activity by Aldo Leopold (1949) in his essay on "Conservation Esthetic."

We need to strengthen and sustain our sense of husbandry. This word is similar to "conservation" in the constructive sense of "management and use." But "husbandry" implies a more personal interest and responsibility for the welfare of the resource. Ellison (1944), in discussing range condition and trends, was getting at this idea when he suggested setting as the goal a balanced complex of climate, soil, vegetation, and animals—fluctuating in response to weather and other factors, but still in rough balance.

Leopold's most important point is the exercise of perception. To paraphrase Ellison's words further: The difficulty is to recognize the "normal" or "optimum" when one sees it. This is a basic problem of range management and one that research also must face.

Ellison's concluding statement is still appropriate:

"The job, as we have to do it today, is in two steps: The first consists in *seeing the evidence.* It is hard to realize how much most of us miss through lack of skill in observation.

"The second step consists in *reasoning accurately.* . . . It is here that a man's knowledge of the processes that shape climate, topography, soil, and vegetation, comes into play. The sounder his knowledge, the better his reasoning and the more reliable his conclusions."

It must be concluded that range management is both a science and an art. It demands scientific facts and the artistic skill of judgment and experience to apply these facts.

MEASUREMENT OF THE HOLOCOENOTIC ENVIRONMENT

David F. Costello

Range research requires measurement of physical and biological attributes in an environment of complexly interrelated factors. This discussion deals with some of the complexities of nature which make measurement difficult. It presents questions which must be answered in research planning. And it considers the need for new approaches and creativity in grazing and ecological research.

THE ENVIRONMENT

The environment in the physical and biotic world is not simple. It consists of a multitude of factors and forces which act and interact with one another. Billings (1952) has emphasized, for example, that vegetation change cannot be interpreted in terms of one factor. Interpretation must consider the environmental complex as a whole. This principle has been termed that of the holocoenotic environment by Allee and Park (1939). It was restated and emphasized by Cain (1944).

In consideration of the holocoenotic principle, Billings (1952) included 15 factors of unequal weight in a circular diagrammatic presentation of an environmental complex. Interrelations between such factors as plants, man, animals, temperature, gravitational forces, radiation, soil, and topographic position were depicted. From a different viewpoint Sampson (1952) depicted the interrelations of different sciences by placing range management at the hub of a wheel with the spokes representing raw materials, integrating organisms, market products, land management, conservative use, and environmental influences.

Hervey (1954), in a modification of Sampson's wheel, included an inner ring of economic and social customs which limit man's range management activities. The significance of these "wheels" is that they emphasize the interdependence of the biological sciences and the multiplicity of knowledge that must enter into the solution of range problems. They also indicate the necessity for applying ecological concepts to practical land management.

The very complexity of nature as opposed to the practical needs of land managers has presented range research scientists with a dilemma. They have been faced with the problem of how to deal adequately with environmental complexity with limited funds and manpower and at the same time produce the simple guidelines demanded by administrators and range managers. Consequently, the tendency has been to study only one or a few environmental factors and to oversimplify range research. Oversimplification has in many instances led to poor interpretation. And poor interpretation has resulted in poor management and in symptomological treatment of effects instead of causes.

ATTRIBUTES FOR MEASUREMENT

One of the problems which faces every researcher who sets out to design a new experiment is, "What shall I measure?" He must define his attributes. What is an attribute? A leaf? A twig? A plant? A unit of living matter, or

litter, or space, or dimension which can be measured in centimeters, or weighed in grams, or estimated in percentages, or transposed mathematically into an index? Here is the place and time for the clearest thinking in all research. Here is the time to choose what should be studied before the experiment is designed in terms of plots, transects, quadrats, exclosures, pastures, replications, and variables.

The Need To Avoid Duplication

Before the researcher can make a proper choice of attributes, he must familiarize himself with what has already been done. Dorothy Brown (1954) has summarized the literature relating to the principal methods of botanical analysis and measurement of plant productivity and utilization. But it is not enough for the researcher to know what has been written. He needs to know what his colleagues have done and have found to be of little use. Although most people are reluctant to talk about their mistakes or wasted efforts, it would be a valuable contribution if more scientists would exchange information about their difficulties as well as their successes in research. Such an exchange might avoid much needless duplication in the development of methodology and the choice of attributes.

The Factors of Choice

At this stage of research planning, the researcher is faced with a multitude of choices. Should he measure plants, or vegetation on plots, and in terms of what—number, height, growth form, weight, competitive ability, adaptation to environment, or ability to withstand grazing? Should he use large plots or small plots, quadrats or points, estimates or measurements? Should he sample the dominant species or all species? Should he study the soil and the weather? And should he study the animals as well as the plants? Should he study single factors or the interrelations of many factors?

The Attribute Itself

One source of difficulty encountered in the use of attributes is their variability. Another difficulty arises from the variety of methods available for measurement of given attributes.

Herbage yield.—Problems of variation in time are exemplified by yield changes as the plant progresses through its successive growth stages. At which stage should yield be measured? And how can yield measured early in the season be reconciled with yield measured later? If yield is measured later how can one account for loss of leaves and twigs earlier in the growth cycle? And what method is best for measuring yield: Clipping, estimating, green weight, dry weight, correlation with height?

Cover.—Measurement of cover is evasive. Should aerial or basal cover be measured? Should it be measured or estimated? Should it be determined with plots, transects, or points? Should layers be measured separately or disregarded? What consideration should be given to the tendency of cover to vary with time of day, with succulence of leaves and stems, with growth form of the plant, and with season of growth? And what does cover mean in terms of yield, of grazing capacity, of soil stabilization?

Frequency.—Since frequency is commonly computed in terms of measurements of other attributes, any error made in the original method is included in computation of the frequency index. Also, every species has its own optimal size plot for the estimation of frequency. But in spite of this, researchers commonly compare frequencies of all sizes of plants from data gathered on a single size of plot.

Utilization.—Even more complicated and frustrating is utilization measurement. Many have pondered the question: How do you measure utilization of a grazed plant, especially when all nearby plants have also been grazed? Or, how do you measure utilization after regrowth has obscured an earlier utilization? And how do you relate utilization to such factors as: Class of animal; growth stage of the plant; availability of other species; palatability; changes in vegetation composition with advance of the season; previous experience of the grazing animal; effects of topography, soil, rainfall; and distribution of animals as affected by fences, salting, herding, and proportions of different vegetation types in the grazing unit?

Indicator value.—Consider, for example, *Achillea lanulosa* which grows from the Missouri River in eastern Nebraska to the Alpine zone on Pikes Peak in Colorado. It has a broad ecological amplitude. It grows tall in Nebraska and short on Pikes Peak. So what does height mean as an attribute? Is it a measure of photoperiodism, length of growing season, soil temperature, or periodicity which enables it to avoid competition with other plants in one place and not in another? Furthermore, abundance of yarrow plants in different vegetation types may be a better measure of grazing disturbance than is herbage yield. Distribution of age classes may indicate successional status in the plant community better than growth form. Measurements of presence may indicate adaptability to different soils better than counts of flower stalk numbers. And so, the question always should be asked about an attribute, "What does it mean in relation to the range problem being studied?"

THE PROBLEM OF GRAZING CAPACITY

Stoddart (1952) had discussed at some length the problem of determining grazing capacity and has concluded that, "No accurate method of grazing capacity determination has yet been devised which does not rely upon experience founded upon comparable range of proved grazing capacity."

Stoddart lists many factors that add to the difficulty of determining grazing capacity. Variability is one of the most important. Annual production of forage varies on every range type from year to year. Seasonal rainfall distribution varies. Distribution of livestock use varies. And generally the numbers of animals vary because the average ranch operator considers it wasteful to graze lightly in years of high forage production and heavily in years of drought. Palatability of any given species varies with time of season and abundance of associated species.

Estimation of range grazing capacity is subject to human error and bias in sampling. Cover is not an adequate index of weight of herbage production. Estimation or measurement of weight production is time consuming and expensive. Measurements made at different growth stages during the course of plant development are not comparable. Converting factors add to the complexity of grazing capacity determination. Chemical and digestibility coefficients cannot be translated accurately into nutritional values. And even if the conversion were feasible, the dietary composition of the animal would be difficult to determine.

Animal forage requirements based on feedlot tests are not comparable to requirements on the range. And if utilization, expressed in terms of proper use, is used as a measure of grazing capacity, we still must answer the questions: What is proper use, how much use is obscured by regrowth, and how do we measure the amount of photosynthetic tissue destroyed by grazing? Add to all these difficulties the matter of determining how much forage is destroyed by trampling, shattering, drying, and grazing by rabbits, rodents, and insects, and we can see why the method of range condition classification has become the most used basis in America for deciding upon stocking intensity.

We have gained by our adoption of the range condition method simply because it makes better use of ecological knowledge than did former methods. But we stand to lose if we subjectively record only obvious aspects of the environment, such as physiognomy, cover, erosion categories, and density, with the concept in mind that these attributes are reliable indexes of the holocoenotic environment. Researchers must be careful not to abandon the science of range management in favor of the art of range management.

COMPLEXITY IN PASTURE STUDIES

A pasture study is expensive, time consuming, usually of long duration, and it may involve cooperation with livestock owners. A well-designed pasture study can be worth the expense. A poorly designed one can be worse than useless since it ties up men for a number of years and produces little applicable information. The pertinent attributes of vegetation are condition, trend, yield, phenology, utilization of most of the species, and vegetation subtypes, and if it is not possible to record these plus soil, topography, rainfall distribution, and available soil moisture, livestock weight gains in coordination with plant development, and previous grazing experience of the livestock, a pasture experiment should not be attempted.

If pastures large enough to support at least 10 head of livestock at the lightest grazing rate are not available, a pasture experiment should not be done. With fewer numbers of animals, cow or sheep psychology, unnatural grazing use patterns, lack of animal replications, and the chance of death losses reducing animal variation to an unmeasurable quantity will be encountered. It should also be remembered that pastures grazed the "same" are not replications. Each pasture will be different from every other pasture. The slopes, exposures, drainage patterns, and location of stock water will be different. The seasonal pattern of rainfall will be different on one end of an experimental area from what it is on the other. The forage types will be different—one pasture will contain more meadow acreage than another. The next pasture will have more shrubs than another. And because of variations of available moisture and weather, productivity in one pasture will fluctuate seasonally more than in another.

If the study plan calls for the same number of animals in each pasture for the duration of the experiment, the question must be answered: What must be done when the pastures will no longer carry a specific number of animals? It is expensive to move fences. And increasing or decreasing the territory for a grazing treatment adds a new variable after the study has been started.

The researcher should remember that a pasture study should represent management in action under designed control. In order to reap the rewards of necessarily high expenditures in time, money, and human effort, he should recognize that he is dealing with the complexity of multiple attributes. He should attempt to study as many

of those attributes as possible and their relations with one another.

The range researcher must contend with many other difficulties inherent in the nature of attributes and environment. He must deal, for example, with a multitude of species, sites, and physical factors. He must deal with processes which are not reversible. Succession, for instance, does not reproduce the stages of range depletion in reverse. And he must deal with many populations that are not normal in the statistical sense. Continued progress in range research, therefore, may require new approaches to old problems and creativity that deals with problems not even recognized in the past.

NEW APPROACHES—ENERGY RELATIONS

There are many new fields for the imaginative range scientist. Some are nameless because they have not been thought of. Some have been considered but not investigated deeply. Some new and useful attributes might be found, for example, through investigation of vegetation patterns, segregation and symmetry in plant populations, lethal factors in the environment, and radiation ecology. There is space here to comment on only one—energy dynamics.

Energy Relations and Productive Potentials

Maximum production potential of a given site is a value that students have long wished to estimate. Little attention, however, has been given by range researchers to energy production, energy utilization, and energy accumulation on areas used by grazing animals. Instead, some have been content to generalize estimates of productivity in terms of more or less intangible range condition classes or of climax communities. Those who have used weight, density, composition, frequency, and other indices for estimating productivity have come closer to true measures of site potential. But even weight or volume of forage consumed is not an absolute measure of what the grazing animal uses in growth and other metabolic processes.

Future research could profitably be devoted to obtaining more precise knowledge of the maximum productive potentials of different sites and to the extent to which this production can be harvested by grazing animals without causing site deterioration. Methods are needed for estimating biological capability of rangelands in terms of gram calories per acre and as percentages of available incoming radiation.

The approach to this field of research would necessitate recourse to the field of meteorology since calculation of available radiation includes such factors as short-wave radiation, black body radiation, mean vapor pressure, and sunshine duration. Methods of sampling would need to be developed, and laboratory processing of samples from range sites would require determination of heat of combustion of leaves, branches, litter, and other energy containing components of the environment.

Planning Studies

Some general principles are already available to serve as a basis for planning studies of energy relations. There is evidence that some ecosystems are more efficient as photosynthetic units than others. The rate of energy accumulation varies as a plant association matures. Also, the growth form of plants is an important factor in the rate of organic matter production. Surface area of leaves, their distribution in aerial space, and possibly even leaf movements caused by wind (Nielsen 1957) may affect energy accumulation and the efficiency of radiant energy utilization.

Since many of the species and plant association attributes are subject to manipulation through grazing management, it is evident that the imaginative range researcher could devise numerous experiments of theoretical and practical value in the field of energy relations. Such experiments might even produce a measure of energy transformation in terms that would be interchangeable between plants and grazing animals.

THE CREATIVE PROCESS

The history of range science shows a tendency in research toward aggregation of subject matter fields. When a new approach to some phase of management is developed, a large number of people are likely to accept the suggestion without evaluation. For example, there was a great upsurge of interest in range survey methods following development of the square-foot-density method. A similar flood of papers followed the publication of several articles between 1939 and 1944 on range condition and trend standards.

More recently, much attention has been given to methodology studies with relative lack of attention to the ultimate purposes for which the range is managed. Over the whole course of range research a great deal of repetition in research has resulted in the same old experiments and the same old designs being applied to new species and new localities. Likewise, there has been a great deal of "hole plugging" or "trouble shooting" research.

This type of research is not bad. "Gap filling" research is needed. But creative research is needed even more. If new frontiers in range management are to be explored, we must parallel in the biological field some of the developments

in the fields of modern physics and chemistry. Creativity is needed.

The creative process is intangible. Roe (1961) describes it as intimate and personal, as taking place at subconscious or preconscious levels, and as being beyond control. Few men are capable of it in high degree, and no one can set it in motion at will. But there are some conditions and a few techniques which may reduce interference with it.

One requirement is "the need for a large store of knowledge and experience. The broader the scientist's experience and the more extensive his stock of knowledge, the greater the possibility of a real breakthrough." The scientist must be given the opportunity to accumulate knowledge and to scan his stock of stored memories. In plain words, he must be given time to think. And if he has a predilection to "stew" and search for ideas while appearing to do nothing, his mental activity should be considered as stemming from motivation rather than laziness or neurosis until proved otherwise.

In motivating creative research it must be recognized that new problems are sometimes best pursued as a single task by a single individual. Organized team research is not wrong in itself, but it is sometimes venerated to the destruction of much that is creative. The blight of research design is that "side roads" tend to be made inaccessible to men with originality. The highly detailed, prefabricated master plan of research, developed by a team or committee, keeps the focus on outward, and usually secondary, matters of application of research instead of discovery of fundamentals. The team-developed research plan may be a masterpiece of compromise—people do not like to offend, or be offended. So the team is motivated by consensus. But consensus doesn't map new country. It leads to mediocrity.

There are plenty of new things left to discover. The world is filled with mysteries and challenges. Research men should be given every opportunity to get at the job of solving these mysteries and accepting these challenges.

TERMINOLOGY AND DEFINITIONS

Vinson L. Duvall and Robert M. Blair

The technical language of range management and wildlife habitat workers is replete with ambiguous terms. This paper points out a number that need standardizing and offers specific definitions for adoption.

TERMINOLOGY FOR VEGETATION MEASUREMENT

The terminology for vegetation measurement is among the most ill defined. *Cover* and *density* are particularly worrisome. They are sometimes used interchangeably, and each has two or more meanings.

In ecological use, cover generally refers to the proportion of ground area under live aerial parts of individual species (Brown 1954, Greig-Smith 1957, Phillips 1959). Crown or foliar spread and basal area are commonly measured to determine cover. In a given plant community, aerial parts of one species often overlap those of another. Thus, the aggregate cover for two or more associated species can exceed 100 percent.

Among range and wildlife habitat workers, cover frequently is used to mean attributes other than the area occupied by individual species. It may refer to ground area overshadowed by plants plus ground not overshadowed but covered by litter (Houston 1954), or to a specific plant community, such as forb-grass cover (Hurd 1959). It has still another connotation—shelter for wildlife (Leopold 1948). While these uses of the term are valid, they are frequently confused with cover as it pertains to proportion of ground area under live vegetation.

Density, to ecologists, commonly denotes the number of plants or specific plant parts per unit area (Brown 1954, Greig-Smith 1957). In range terminology it frequently expresses the proportion of area occupied by either crown or foliar spread or by basal area (Cooper 1959, Dasmann 1948, Hurd and Kissinger 1952, Parker 1954). Thus, density, as defined by range workers, is synonymous with the ecologists' term cover.

It is unfortunate that cover and density—terms that should have useful, independent meanings—have become confused. As a start toward standardization, it is proposed that cover, when used alone, denote the proportion of ground surface occupied by vertical projection of live aerial parts of plants. When intended to convey a different meaning, cover should be prefaced by the appropriate modifier, such as *forb*, *litter*, or *game*. Density, then, would be reserved to express number of plants per unit area.

The term *ground cover* has found wide application in vegetation analysis. It has been used

to designate the shrub and herb layers in forest stands (Allred 1950, Society of American Foresters 1958), and as a synonym for cover (U.S. Forest Service 1959). It should refer to the proportion of ground area under live aerial parts of plants, plus that occupied by nonliving materials such as litter, stones, logging debris, and erosion pavement (Halls et al. 1960, Hurd and Kissinger 1952, Parker 1951).

The term *vigor* denotes plant health or vitality. Because vigor is manifested in many ways (Pond 1960), it is extremely difficult to determine objectively; hence the popularity of shortcut measurements in which vigor rating is based on only one or two plant attributes (Parker 1951, Pond 1960, Short and Woolfolk 1956). Because these evaluations sometimes provide only rough guides to plant health, they should be labeled *vigor indices*. *Vigor*, then, would be reserved for thorough assessments of plant health or vitality.

Moderate grazing generally implies the optimum intensity of range utilization. In experiments that compare three rates of grazing, however, the middle treatment is frequently designated as moderate, regardless of whether it represents optimum use. The terms *heavy grazing* and *light grazing* are similarly misapplied, and in extreme cases light grazing may refer to an intensity that actually exceeds optimum.

This problem can best be solved by reserving moderate for grazing levels that are known to be near-ideal for specific range conditions. Heavy and light should be applied only to grazing levels that are substantially above and below optimum.

TERMINOLOGY FOR RANGE PLANTS

A number of definitions associated with range and habitat plants need clarification. The widely used terms *herbs* and *herbage* are often a source of trouble. Some authorities define herbs as flowering plants in which stems do not become woody or persistent, but die annually after a season of growth or after flowering (Bailey and Bailey 1947, Society of American Foresters 1958). Forbs and grasses are included (Society of American Foresters 1958).

These definitions have two shortcomings. First, no provision is made for evergreen, perennial forbs, such as partridge-berry (*Mitchella repens*) and certain members of the wintergreen family (Pyrolaceae) that have nonwoody, persistent stems. Second, inclusion of forbs and grasses may be construed as meaning all grasses, including the bamboos, which have persistent, woody stems. In view of these exceptions, it is recommended that *herb* be defined as any flowering plant except those developing persistent woody stems above ground. This would include most forbs, grasses, and grasslike plants. Notable exceptions are the two bamboo species that occur commonly on southern and southeastern ranges. *Herbage* would be the total aerial parts of herbs, individually and collectively.

Misapplication of the terms *forb* and *weed* is perplexing. Forb has been used synonymously with "herb or weed," and a weed has been defined as any herbaceous nongrasslike plant occurring on the range (Dayton 1960, Society of American Foresters 1958).

A *forb* can be described more accurately as any herb other than grasses and grasslike plants, whereas a *weed* is an unwanted plant that does more harm than good. These terms should never be used synonymously, because forbs often include the most valuable species on the range, as well as the most noxious. Weeds, on the other hand, encompass undesirable herbs, shrubs, and trees.

Shrubs are difficult to delineate precisely, because their growth habits are indefinite. They have persistent woody stems and relatively low form, and they generally produce several basal shoots instead of a single bole. At times, differentiation between trees and shrubs must be arbitrary, as both growth forms occur in some species. However, seedlings, saplings, and suppressed individuals belonging to species that ordinarly attain tree size and form should not be classed as shrubs.

The literature yields divergent views about *forage*. Agronomists and animal husbandmen generally class as forage hay, silage, fodder, and unharvested pasture and range vegetation suitable for animal consumption. For reasons unknown, some range men rule out all harvested vegetation (Allred 1950, Society of American Foresters 1958). In the interest of standardization, forage should include all vegetation, harvested and unharvested, that is available and acceptable to animals, except mast, seeds, and fruits of woody plants, and harvested grains.

The principal source of forage on many livestock and game ranges is *browse*—the leaf and current twig growth of shrubs, woody vines, and trees that is available for animal consumption (Allred 1950, Halls et al. 1957). Some authorities limit the term to twigs, shoots, and leaves that are acceptable to or cropped by livestock and game animals (Brown 1954, Dayton 1931, Hanson 1962, Sampson 1952). This definition disregards the unacceptable parts, and leaves them without a name. The former definition is preferable because it admits both acceptable and unacceptable woody plant parts, just as acceptable and unacceptable grasses, grasslikes, and forbs are classed as herbage.

Differences of opinion occasionally arise regarding the inclusion of fruits and berries as

browse. In view of the need for more objective and precise terminology, it is recommended that browse include only the vegetative parts. Mast, berries, and other fruiting bodies can be grouped more logically into separate food categories.

A discussion of terminology for range and habitat plants would be incomplete without a clear definition of *feed.* Any edible material having nutritive value can be classed as feed. Common examples are forage, mast, fruit, grain, grain products, oil-seed products, and vitamin and mineral supplements. *Feed* and *food* can be used interchangeably.

TERMINOLOGY FOR FORAGE-PRODUCING LANDS

Terminology of grazing land is often vague and misleading. Terms that were once specific have become broad and complex. *Grassland,* for instance, was previously reserved for lands on which one or more grass species comprised a major part of the vegetation. On many such lands, plant succession has changed the character of the vegetation. Forbs and shrubs now dominate; still, these lands are frequently referred to as grasslands.

Under the modern concept of so-called grassland agriculture, areas supporting legume forages are often classed as grasslands (Ahlgren 1949). This is misleading. A more appropriate term is *herbland*—land supporting stands of vegetation dominated by grasses, grasslike plants, forbs, or combinations thereof. Likewise, areas dominated by shrubs or other low forms of woody vegetation should be classified as *shrubland.* These terms are definitive and their application should be greatly expanded, leaving the term grassland exclusively for vegetation consisting primarily of grasses.

Habitat is the natural abode of a plant or animal. It consists of all biotic, climatic, and soil conditions or other environmental influences that affect life.

Range, as used to identify grazing lands, should include land producing native forage for livestock or big-game animals, and also lands that are revegetated naturally or artificially to provide a permanent forage cover that is managed like native vegetation.

In taxonomy, the term *range* denotes the area over which a plant or animal taxon occurs. In zoology, it sometimes delimits the area occupied by an individual animal during the normal course of life, although the term *home range* is preferable for this purpose.

Range site refers to an area where the environmental complex is sufficiently constant to support relatively uniform vegetation, usually permitting uniform grazing management.

The term *pasture* was once applied freely to all kinds of grazing land. Recently, it has been used in a more restrictive sense. Pastures should now be considered as intensively managed grazing lands, usually supporting introduced forage species and receiving periodic cultural treatment such as tillage, fertilization, mowing, and irrigation. Thus, most pastures are readily distinguishable from rangelands, but occasionally borderline cases must be arbitrarily classified.

Subdivisions of the range are frequently referred to as pastures. To avoid confusion, it is recommended that this application of the term pasture be discontinued and the term *range unit* used instead.

SUMMARY AND CONCLUSION

The foregoing are samples of the terminology needing clarification. Many other terms in common use are equally confusing.

Specific meanings have been proposed for all terms discussed. These definitions are summarized below. Their acceptance is recommended as a step toward a detailed glossary—a prime necessity for standardizing terminology. A logical approach to a glossary would be through action of a joint committee from such organizations as the American Society of Range Management, the Wildlife Society, the Soil Conservation Society of America, and the Ecological Society of America. Until standardization is attained, authors should carefully define all terms that might be misconstrued. A careful search of literature will frequently reveal acceptable terms, eliminating the need to coin new terms that would add to the confusion.

Browse.—That part of leaf and current twig growth of shrubs, woody vines, and trees available for animal consumption.

Cover.—The proportion of the ground surface occupied by vertical projection of live aerial parts of plants.

Density.—The number of plants or specific plant parts per unit area of ground surface.

Feed.—Any edible material having nutrient value.

Forage.—All harvested and unharvested vegetation, except mast and fruits of woody plants and harvested grains, that is available and acceptable to livestock or game animals.

Forb.—Any herb other than grasses (Gramineae) and grasslike plants (Cyperaceae and Juncaceae).

Grassland.—Any land on which grasses dominate the vegetation.

Ground cover.—The proportion of ground surface occupied by vertical projection of live aerial parts of plants, plus that occupied by nonliving matter such as litter, stones, and logging debris.

Habitat.—The natural abode of a plant or animal, including all biotic, climatic, and soil conditions or other environmental influences affecting life.

Herb.—Any flowering plant except those developing persistent woody stems above ground.

Herbland.—Any lands on which herbaceous species dominate the vegetation.

Home range.—The area over which an individual animal travels during its normal life.

Moderate grazing.—The intensity of grazing that will sustain maximum livestock production consistent with other land uses and the conservation of resources.

Pasture.—Grazing lands under relatively intensive management, usually supporting introduced forage species and receiving periodic cultural treatment, such as tillage, fertilization, mowing, and irrigation.

Range.—In livestock and big-game production, all land producing native forage for animal consumption, and lands that are revegetated naturally or artificially to provide a permanent forage cover that is managed like native vegetation.

In taxonomy, the area or areas throughout which a plant or animal taxon occurs.

Range site.—A range aera over which the environmental complex is sufficiently constant to support relatively homogeneous vegetation, usually permitting uniform grazing management.

Range unit.—A range subdivision that is grazed as a unit.

Shrub.—A plant that has persistent, woody stems and a relatively low growth habit, and that generally produces several basal shoots instead of a single bole.

Shrubland.—Any land on which shrubby species dominate the vegetation.

Vigor.—The state of plant health or vitality.

Vigor index.—An estimate of plant vigor based on measurement of one or a few attributes.

Weed.—Any plant growing where unwanted and more harmful than beneficial.

SOME LESSONS ON ELECTRONIC DATA PROCESSING FOR FOREST SERVICE RESEARCH

Floyd A. Johnson

We have had 8 years of experience in electronic data processing (EDP) at the Pacific Northwest Forest and Range Experiment Station. During this time we have made many mistakes, but we have also learned much.

The first lesson and one of the most important facts we have learned about EDP is that it is best to have our own programers. Ideally, each project worker should be his own programer, and the time may come when this ideal is realized. Even now, there is a sprinkling of project workers throughout Forest Service Research who do their own programing. We have one of these at our Station, and there are at least a few others throughout the country.

The ability to program is a tremendous asset for any researcher. He doesn't have to waste his energy explaining his problem to someone else; but most important of all, he gains additional insight into his problem in the actual process of programing.

However, programing techniques have been evolving so rapidly that it takes an exceptional person to be both a subject matter specialist and an electronic computer programer. When programing techniques are more settled, maybe we can expect more people to have both capabilities.

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Perhaps it would be more realistic to settle for less, at least for the next few years. At this lower level we might expect to have one programer on a service basis in each subject matter division.

There is a distinct advantage in having a programer who is intimately familiar with the problems and procedures of a particular division. He can operate with considerable independence and doesn't need to be educated by the project workers in that division.

At the PNW Station, all programing is done in the Biometrics Section by two full-time programers. They are available to anyone, but their time is usually appropriated by the more aggressive divisions. Two programers are not enough to do our programing job. A difficult program can take several months to write, correct, and test. This limits us to very few completed programs each year. In 8 years we have completed 25 programs, and there are about 10 more waiting to be written.

Another difficulty is that as soon as a program has been completed, it is likely to be obsolete. Once project workers see what the computers can do for them, they immediately want more

programs or changes made in what they have been given.

Both programers at the PNW Station are mathematicians. In addition, one of them has had considerable experience in each of the subject matter divisions, and this has greatly increased her effectiveness. She doesn't have to be told what a lumber grade is or what d.b.h. means. She often alerts project workers to the possibilities of increased information from their data and to errors in their statistical procedures.

The second lesson from our PNW experience with EDP is that Experiment Stations like ours should not become burdened with hardware. We do not want to own or rent machines. We don't want to worry about repairing them, keeping them busy, accounting for time, or sweeping out the computer room. Instead, we want to get in and out quickly and pay only for the specific jobs that we have done. A disadvantage in having machines of our own is that we are likely to be forced into soliciting outside jobs just to keep the machines occupied. Unless we are very careful, machines may turn our research organization into a data processing service.

At the PNW Station we use machine facilities that are the responsibility of the administrative branch of the Forest Service. We can't always get things done just when we want them, but at least the cost is reasonable.

Fortunately, electronic computers and other data processing equipment are becoming increasingly available. In addition to our Forest Service establishment in Portland, Oreg., which has a 650, the Bonneville Power Administration just a few blocks away has a data processing center with another 650. The Bureau of Public Roads in Portland has a 1401 and a 1620, both of which are available to us. The Corps of Engineers in Portland has a 1410, a 1620, and a 650. Several savings banks in Portland also have electronic computers with all the necessary supporting equipment, and IBM's Service Bureau Corporation is always available. Most of these agencies are happy to accommodate us, and the rates are getting cheaper as time goes on.

The point we are making, of course, is that we don't need to own machines—they are abundantly available everywhere.

The third lesson from our experience with EDP is that, while we don't want to own or rent machines, we do want them close by. There has been agitation from time to time for establishing computer headquarters for all Forest Service Research at, perhaps, two locations—one in the East and one in the West. Frankly, we do not see how this could work. In our opinion, the machines must not be more than a few minutes away from the programers.

The prospect of correcting a program or even making production runs by remote control would, in many cases, be unthinkable. Would a programer take a long trip every time he had a new program to correct or test, or would he send a detailed memorandum of instructions to machine operators at the computer installation? If a program error was revealed during a production run, would the operator stop the machine and make a long distance telephone call to the programer or project worker?

Sometimes, with established programs, we have operated by remote control. We have made considerable use of a 704 machine in Tennessee by courtesy of the Southern Forest Experiment Station and with programs developed by L. R. Grosenbaugh. However, for most of our work, there is no alternative to having computers close at hand, and we should vigorously oppose all attempts to centralize processing of research data.

Lesson four from our experience is that it pays to exploit existing programs. Programing is an ordeal to be avoided if at all possible, and we always determine whether the job we want has already been done by someone else. I have already mentioned our use of L. R. Grosenbaugh's programs. One of these was the subject of a Southern Station publication (Grosenbaugh 1958) and has received considerable publicity. To the best of my knowledge, it is unique among computer programs for multiple regression analysis in that it provides a separate solution for every possible combination of independent variables. This leads to certain advantages over other multiple regression programs.

We have also used many other computer programs which were developed by the Southern Station, by other Federal agencies, and by private agencies such as IBM. I suspect that one reason we haven't made even greater use of existing programs is that we aren't aware of them.

This leads to the fifth lesson, which is that it pays to write a formal report covering specifications for each program. If this is not done, others will remain unaware of the program, and, even worse, the program may quickly become incomprehensible, even to those who wrote it.

At the Pacific Northwest Station we have adopted the policy of writing a report for each of our programs, covering detailed input and output specifications, assumptions underlying the calculation procedures, formulas, machine operating instructions, and any other information that could be useful in getting the data ready for processing or in interpreting results. Whenever these reports are likely to be useful to others, we give them formal treatment and reproduce them for limited distribution. If a program is likely to be especially useful to others,

we publish the report as a Station Paper and give it wider distribution.

There has been a very encouraging response to these published reports. Apparently, interest in EDP is tremendous not only in this country but also overseas. In one of these published reports we offered to send a program deck to anyone who was interested, and we soon found ourselves in the business of reproducing punchcards.

We have encouraged the idea that in writing computer programs we are actually doing research, and that reports on these programs are actually research publications. This is consistent with the idea that research is any activity involving inquiry which leads toward the solution of some problem.

In any event, I am convinced of the necessity for having a formal report on each program. I would like to see this report-writing phase made standard procedure throughout the Forest Service in order to avoid duplication of effort. We have profited tremendously by programs which have been developed at other Stations.

The sixth lesson from our experience with EDP is that there is a definite advantage in fragmentizing EDP programs whenever a problem is either too complex for the machine at hand or we are unable to see all the directions that a solution might take.

In such cases we have learned to break the problem into parts. For example, when we first started to program for the PNW Forest Survey, our idea was to feed in basic field data on trees and take out finished tables ready for publication. It took us a long time to realize that either we didn't know enough about what we wanted or we didn't have the right kind of equipment. Once we realized this, we started to write small programs for parts of the complete job. For example, we wrote one program for the growth phase of Forest Survey and another for the inventory phase. In the end, we had eight programs, each covering a separate phase of the entire Forest Survey analysis procedure.

I believe many EDP failures can be attributed to an unwillingness to do a small part of a big problem. There is probably some prestige value in a single program that does everything in a grand manner, but my inclination is to get the show on the road by doing what can be done and doing it now.

The seventh lesson from our experience is that a program should never be taken for granted.

Programing errors are to be expected, and every new program should be tested as thoroughly as possible. This usually means manufacturing a hypothetical set of data which will force the machine through every channel in the program. Then it means creating by longhand calculations a complete set of results for this hypothetical data which can be compared against the machine output.

Testing is a laborious and annoying task, but it is of utmost importance. The net result of an improperly tested program could be a tremendous pile of erroneous and misleading information produced at dazzling speed.

The eighth and most important of all the lessons from our PNW experience with EDP is that researchers in general are insufficiently specific in defining objectives for their studies. In many cases programers are not only faced with the relatively simple job of filling the gap between input and output specifications—they must also help establish the output specifications. In effect, they must help the researcher decide what he wants to know.

This need is very common, and I am sure that it is not unique to the PNW. I sometimes believe the most important contribution of EDP to research is that it forces researchers to be specific.

The last point I want to make is not a lesson from our experience. Rather, it has to do with a feeling I have about EPD. I believe electronic machines offer the possibility of extending our horizons in research far beyond the limits that were possible before such machines were available. Once we really appreciate this powerful new tool, we are going to uncover problems that we never knew existed before, and we are going to find new and more clear-cut solutions to old problems. There are already some indications of this in Forest Service research. L. R. Grosenbaugh's "all possible solutions" for multiple regression seems to be a step in this direction. Another is the Palley-O'Regan (1961) use of electronic computers for tests of forest sampling methods, which was described recently in Forest Science.

There are also some excellent examples of imaginative applications of electronic machines in other fields. In the field of medicine we hear about diagnosis by EDP. The idea here is that disease symptoms and attributes of patients would be used as input data, and the computer would act as a diagnostician.

You have probably all heard how airline companies have been using electronic computers for making reservations and assigning seats. Maybe you haven't heard how General Electric uses old electronic machines to build new ones.

Perhaps these examples will suggest what I have in mind when I say that EDP has tremendous possibilities for increasing the scope of range research.

COMMITTEE REPORT ON INTRODUCTORY SESSION

The introductory session explores research philosophies and analyzes a few general features of our range research effort. By providing this background it serves as a springboard for succeeding sessions of the conference. These four papers are composed of general topics that may apply to all other sessions. They review important procedures and concepts and represent a somewhat orderly progression of ideas on why range research is conducted, difficulties in measuring attributes of the range community (holocoen, complex, ecosystem, or biosystem), terminology for effective communication, and ways to improve the collection and processing of data.

The ultimate goal of range and wildlife habitat research is to develop management practices that will achieve or maintain optimum livestock or wildlife production, consistent with other resource values. This is an exceedingly complex problem. In our efforts to deal with it, we have sometimes oversimplified, and this has led to poor interpretation and subsequently to unsound management. Yet much has been accomplished: Some good management systems have been developed, helpful criteria for utilization established, effective revegetation practices devised, and substantial amounts of fundamental information produced.

Now, circumstances are becoming more favorable for doing research. Our storehouse of basic information is ever growing. Manpower and facilities are increasing. Thus equipped, we are obliged to intensify our efforts to learn how to analyze biotic communities, recognize patterns of change and reasons for those changes, and know the attributes that characterize these features and functions and how to measure them. These are more or less the objectives of classic ecological study, but progress can be accelerated if they are approached by new avenues, and if more emphasis is placed on openmindedness and creative thinking.

In evolving our research program, we have continually tried to make our methods more objective and our data more quantitative and consequently more repeatable. The need for these elements is unquestioned. Still, we should not lose sight of the fact that much has been accomplished by qualitative investigation and that judgment and intuition can and should be included in the scientific method. This is especially true in applied phases of range research where magnitude and variability of the range areas prevent adequate measurement and sampling. Here observation and logic, effectively combined with experimental evidence, can accelerate solution of practical problems. Subjectivity is particularly important in the selection of areas to be studied, for without such selection an experiment may be doomed to failure before it is even begun. Areas chosen for intensive study should be generally typical of broad areas to which results will be applied, yet they must be deliberately selected to avoid a wide range of variation that would confound experimental results. Range research, then, is both an art and a science, and progress will be limited if either is consistently ignored.

In this conference we are primarily concerned with the selection and measurement of attributes of the range community, particularly those of vegetation and soil. Answers are needed for innumerable questions. For example: What vegetation or site attributes should and can be measured and for what purpose? What is the best measure of dominance or stand composition? How equivalent are the various measures? Which attributes best express range condition and trend?

Without the use of meaningful attributes and satisfactory methods of measurement, little progress could be made in understanding the plant community; consequently, development of range management practices would be limited to empirical methods. Past research and experience have provided much information to guide selection and measurement of attributes, but the job is far from complete. Discussion in subsequent sessions of this conference should more clearly define this problem and suggest ways of solving it. One way would be to publicize our negative results and mistakes, at least among our own research group.

A question that will receive subsequent deliberation is how to conduct range and wildlife habitat experiments, but in this introductory session we are merely concerned with *why*. One reason for conducting grazing studies, for example, is that forage production alone may not directly express grazing capacity; consequently, actual trials are needed to develop satisfactory correlations between range attributes and capacity to produce livestock and game. Furthermore, grazing trials afford records of change in the range communities; various intensities of stocking or other treatments provide usable information on patterns of improvement and deterioration—or in other words, indicators of condition and trend. Grazing experiments also provide tests of the true worth of management systems, which cannot be determined except under carefully controlled conditions. These are the justifications for our search for better meth-

ods to measure the influences of various grazing treatments on both site and animal.

As has been brought out many times in the past, a real need in range and wildlife habitat research exists for more precise terminology, particularly for vegetation attributes. Certain widely used terms mean different things to different people, and unless accompanied by individual definitions, confusion is introduced. Since the Forest Service Division of Range and Wildlife Habitat Research is the largest single unit doing such research, some degree of standardization could be achieved if we could arrive at acceptable definitions for some of the most troublesome terms.

Another obvious need in range research is the development of ways to facilitate the processing of data. This means training project workers in programing techniques for electronic computers, or at least hiring programers who can work with and for the project workers.

Of vital importance for each Station is immediate access to electronic computers and ancillary equipment, such as punchers, sorters, and verifiers. Centralized computer establishments at some distant location are definitely not in the interests of maximum progress in research.

Finally it means writing and distributing formal reports covering those computer programs that are written for specific research projects. These reports can be responsible for avoiding costly duplications of effort and should be encouraged.

Electronic computers have much more to offer research than merely a fast, economical, and accurate way to process data. They offer the possibility for research of a new and exciting kind in developing statistical theory and application. This possibility remains largely unexploited. It needs project workers who are trained in the techniques of electronic computers and who have imaginations to match their powerful new equipment.

RECOMMENDATIONS

1. A clear, concise statement of specific objectives of study should always precede selection of methods to be used.
2. Each Experiment Station should have local access to electronic computers and other data processing equipment.
3. Scientists in the Division of Range and Wildlife Habitat Research should cooperate with the American Society of Range Management in evolving a glossary of range and wildlife habitat terms.

R. S. Campbell
D. F. Costello
V. L. Duvall
F. A. Johnson
R. S. Rummell
J. P. Blaisdell, *Chairman*

Vegetation Measurement and Sampling

HERBAGE YIELD AND ITS CORRELATION WITH OTHER PLANT MEASUREMENTS

Jack N. Reppert, Ralph H. Hughes, and Don A. Duncan

Herbaceous plant responses may be evaluated in many ways, but researchers generally agree that weight is one of the best quantitative measures (Stapledon 1913; Hanson 1930). Other plant measures may be important in the way that they are related to or are indicative of herbage yield.

Knowledge of herbage yield is seldom an end in itself, but is usually important only as it is related to some grazing animal product or ecological response. Objectives which are served, with varying degrees of success, by measures of herbage yield can be listed in five questions:

1. How do range improvement practices or malpractices affect herbage yield? Many practices can be included, such as fertilization, type conversion, reseeding, and rodent control, to mention a few. Here the yield of herbage may be the end product of evaluation.
2. How does grazing treatment affect herbage yield? The information may be determined for a given time, seasonally or from year to year. The study of effects of grazing intensity or system of grazing fit here.
3. How does grazing a known yield of herbage affect livestock weight response? Included are questions of live-weight increase per acre as well as individual animal performance based on the yield of important components of the herbage crop.
4. How does the quantity of a herbage crop affect grazing capacity?
5. How well do yields reflect the impact of the weather year?

METHODS FOR MEASURING YIELDS

Difficulty in measuring yields is influenced by such factors as the type of vegetation, particular season or year, caliber of workers, and money (or time) available. Much hinges on the ability of workers to define clearly and consistently the plant character to be measured. It is also important that plant characteristics be measured with adequate precision.

Three general methods are available: (a) direct measures (either harvested or visual estimates) of plant weight, (b) indirect measures of plant characters that are associated with actual weight, and (c) combination of direct and indirect measures.

Direct Measurements

Direct measurements of yield, for the most part, involve plots of known area, although some work has been done with plotless methods.

Weight from clipped plots.—Harvesting herbage on plots of known area has been a standard approach for many years. In theory, no approximations are involved; clippings are collected, dried, and accurately weighed. The method requires little training or concentration. It can be fairly rapid when sorting of species is done later in the laboratory. The method is basically simple, but a thorough understanding and diligent performance of the several tasks in the collection phase are needed to insure accuracy. Some of these steps are as follows:

1. Unbiased sample unit placement within limits set forth in objectives. The field worker has some chance in selecting location of sample units. A system which eliminates most chance of selectivity and leaves him with a straightforward procedure is most desirable.

2. Correct and consistent procedures for delineation of plot boundaries. Rectangular plots may be more efficient (American Society of Agronomy et al. 1952), but circular and square plots are often favored because they minimize the error of "edge effect." Adequate guides are necessary for objectively deciding whether a plant is inside or outside the plot boundary.

3. Clear understanding of species to be sampled. Study objectives may call for harvest of only "palatable herbage" (Reed and Peterson 1961). Therefore, plants in this category must be easily recognized by the investigator.

4. Definition of portion of plant to be sampled. This is often "current year's growth." In some cases plant parts fall off or become shattered before collections are made. Clear instructions should be given for handling this kind of plant material.

5. Selection and adherence to the clipping height. It is best to clip fairly low if the aim is to include nearly all herbage available to grazing animals, or at ground level if the purpose is to include the entire production (Lommasson and Jensen 1938; West 1938). As clipping approaches ground level, fine soil particles are more easily picked up. Yet sometimes more than half of the herbage is below heights of 1 or 2 inches.

6. Careful plot identification, weighing, and recording. If all the tasks mentioned before are properly done, final handling of the plant material is a simple procedure. A final check of the material at this stage will insure accurate data.

Weight-estimate.—This method eliminates clipping or harvest of plant material and depends upon the ability of the field worker to estimate the weight (Pechanec and Pickford 1937). Saving in time, an obvious advantage, permits a relatively large number of estimates as compared to actual harvest. Training requirements vary greatly with area, degree of species breakdown, and ability of the estimator. Time spent training must be added to estimation and clipping times if an accurate comparison between the two methods is desired. Time required for collection of material for conversion to dry matter should be added.

Factors listed under clipped plots as possible sources of error apply with equal force in herbage weight estimates. Several other factors should also be considered:

1. Specific standards of training. Training should be conducted in two phases—*before* and *during* the field sampling (Hughes 1959). Before sampling, estimates of production should be compared with actual weight of clipped material. During the survey, the precision of the estimator should be checked without his knowledge. Otherwise, two kinds of estimates may result: very thoughtful estimates when he knows they will be checked, and less careful ones when he knows they will not be checked.

2. Drift of the estimates. During the day some workers will tend to shift their mental standards of weight and drift toward an extreme, either high or low (Reid and Pickford 1944; Smith 1944). This drift may happen during the week with poor estimates at first because of weekend rest, improved estimates at midweek from training, and poor estimates by the weekend because of fatigue. Changes in tendency of the estimate may occur on a seasonal or yearly basis also. The error may be reduced by carefully observing and frequently training field workers.

3. Error from changing moisture content of green herbage. Either oven-dried or air-dried weights are usually the goal, and time is saved if

dry matter can be directly estimated in the field. Training and checking are then more involved because the trainee must dry the samples for comparison with his estimates. The estimation of green weights and later conversion to dry weight is often a more satisfactory procedure. Different species and even the same species on different days will have a different ratio of green to dry material (Hilmon 1959). This requires collection of herbage samples during the survey, as needed, for later conversion to a dry-matter base.

4. Problems of the mind and body. Happy field crews function most effectively, and people with "problems" can interject unnecessary errors. Weight estimates are especially vulnerable to human error. A common fault might be called "preconceived notions." The experienced worker is more vulnerable to this type of error than a person without training. For example, a man knows the average yield of a range in a good year, and he is reluctant to estimate plots much lower or higher than the expected. The result is much less variance in the values for plot yield than actually exists, and the mean of the estimates may also be biased higher or lower than the actual because of the preconceived idea. Other human frailties, such as a sore back or a remark by a fellow worker, can easily influence the ability of the estimator.

Actual plot weight and weight estimate combined in double sampling.—This combination of methods makes use of the speed of visual weight estimates, but maintains control and an estimate of error by clipping and weighing vegetation from some of the plots used for estimating vegetation weight (Wilm et al. 1944). The relationship (usually a linear regression or a simple ratio) between estimated and actual weight on the double-sampled plots is used to adjust or correct the large number of plots where only an estimate of weight was made. This procedure includes all the chance of errors that were listed under both actual weight and weight-estimate methods, although much of the inaccuracy in estimation is corrected by the double-sample procedure. In addition, new considerations are now important concerning the way in which the two methods are combined.

1. Standards of training. The estimator should be trained before he begins a survey. He should not compare results with the clipper during the course of the survey because this introduces bias in the regression equation. Individuals introduced to the double-sampling method should fully understand the proper field procedures and the theory behind the method. A thorough understanding of the sources of error in double sampling is essential.

2. Proper application of the regression coefficients. In the pine-wiregrass grazing type, experience indicates that the regression coefficient in double sampling varies from sampling time to sampling time for the same species and estimator.[1] For example, the regression coefficients for pineland threeawn (*Aristida stricta*) from data taken between December 1, 1958, and March 1, 1959, on freshly burned range before cattle entered and at four intervals thereafter were 1.5288, 1.1944, 1.0513, 1.1613, and 1.0323. These regressions varied significantly although surveys were made just 3 weeks apart, and total volume was very similar. Consequently, under the conditions of this study, separate double-sample data must be taken for each survey regardless of the time interval between. Also, there was a significant difference in regression between species or groups. Thus, separate regressions should be computed for each; a regression computed for total herbage will not apply to components.

Actual total plot weight and species weight estimate combined.—As in double sampling, this method has the speed of estimation and the accuracy of true weights. At the "all-species level" a harvested plot is weighed, and at the "individual-species level" only a visual estimate of weight is made. Control is applied to all-species estimates in that their sum must equal the total weight. All the work can be done in the laboratory after the plot harvest. The advantage is that many more samples can be examined in comparison with hand separation of each plot into species and groups (Wagner 1952). In the California annual-type, estimates can be made in the laboratory of species weight for 6 to 9 square-foot plots, while actual species separations and weights are made for one plot. Special considerations, in addition to those listed under actual weight method, are needed to keep the estimates as accurate as possible.

1. Skill is a requirement for making estimates. It can be developed only through experience, so that while new people are learning, the speed advantage of the method may be small.

2. Training is vital in this procedure not only to develop skill but to maintain it. Frequent checks are required each day to verify estimates by actual separation and weighing.

Actual weight of a single plant or plant shoot.—This is a plotless method in which the individual plant unit (a whole plant or plant shoot [2]) is collected and weighed. To convert weight of plant shoots into weight of herbage per unit area,

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[1] Hilmon, J. B., and Hughes, R. H. (Unpublished data on file at U.S. Forest Serv. Southeast. Forest Expt. Sta.) 1962.

[2] A plant shoot is defined as a single plant stem or major branch coming from below, one-half-inch height.

the number of plants per unit area (density) is required. Variance of individual plant weights is rather high on California annual ranges, but variance may be lessened by using plant shoots. Even so, variance may be as much or more than that for clipped square-foot plots. A test of the plant shoot-density method in the California annual-type gave an estimate of yield 26 percent below the clipped plot yield of the same area.[3]

Shoot collection permits on-the-spot species separation and eliminates subsequent sorting of dry or partly dry plant material. Shoots may be collected by almost any rapid method of sample placement. Individual shoots may be pooled for estimates of weight variance.

Errors can be made in sample unit placement and definition, species to be sampled, "state" of species to be collected, clipping height, and weighing (an analytical balance is needed for single-shoot weights). These were discussed under clipped plot procedures.

Indirect Methods of Estimating Herbage Production

These methods are concerned with the relationships between selected plant factors and production. They are valuable only if several conditions exist. Any factor exhibiting a close relation to yield should be clearly defined to facilitate easy and accurate measurement. A method of measurement without bias and of satisfactory precision is required for the factor. Relation between the variable and actual yield, along with acceptance levels of this relation, must be decided upon. Continued use of a satisfactory relation, expressed in prediction equations, should take place only after the stability or persistence of this relation is determined for different seasons, years, treatments, etc. An assumption that a good relation will apply over a general area can be a serious error. The relation may still be good, but it may differ in degree. Some indirect measures of yield are listed and discussed below.

Height.—Plant height, whether of a single species or all species, may be closely related to yield (Frakes 1959; Heady 1957; Reppert et al. 1962). During the early stages of plant growth when a range approaches readiness for stocking, height is an appropriate index of yield. At that time, height is a critical factor in determining range grazing capacity. Plants in early stages, in contrast to mature plants, are often simpler in structure (Kelley 1958). At the San Joaquin Experimental Range in California, however, the relation remained about the same regardless of growth stage (table 1).

The objective of a study is a primary consideration in deciding just how to measure height and what to measure. For example, height of plants in their natural position may be most suitable for range readiness surveys, and full plant length may be more suitable as a measure of total yield. Visual estimate of height is of limited value in research because of difficulty in making accurate estimates, although it may be useful if actual measurements are not feasible.

TABLE 1.—*Linear regression coefficients (b) and correlation coefficients (r) between air-dry weight and height at early stages and later stages of plant growth, San Joaquin Experimental Range, Calif.*

Vegetative conditions	Heights measured	b	s_b	r	Coefficient of determination
					Percent
Very early vegetative stage	Grass height + filaree height ÷ 2	4.674	0.740	0.747	55.7
Later vegetative stage	Grass height + filaree height ÷ 2	4.349	.612	.797	63.5
Plant maturity	Average of all species	2.712	.212	.800	64.0

Cover.—For some species, percentage ground cover shows good relation to yield (Pasto et al. 1957). Measurements of cover may be based on certain plant parts (base, leaf) or on the entire plant (foliar cover). Foliar cover appears better related to weight than is cover of some plant part, such as the base. However, basal cover may show good relation to yield for such vegetation as bunchgrass.

Height and cover combination.—This procedure logically brings together "depth" and "area" measurements of herbage. The product of the two is a rough index of volume. It is well known that volume is related to actual weight (Crafts 1938). In one study of California an-

[3] Reppert, Jack N., Morris, M. J., Duncan, D. A., and Reed, M. J. Plant shoot weight times density as an estimate of yield on California annual-type range. (Unpublished report on file at U.S. Forest Serv. Pacific Southwest Forest & Range Expt. Sta., Berkeley, Calif.) 1962.

nual-type, 29 to 98 percent of the variation in yield due to height times cover was accounted for (Evans and Jones 1958). At the San Joaquin Experimental Range 28 to 84 percent of the variability in yield was accounted for by height times cover (Reppert et al. 1962).

Diameter.—Diameter can be converted to measures of area. Circular stems or round clumps are easily used in this way. In some cases diameter can be converted into the same units as measures of cover (basal cover). Also, diameter measurements of various plant parts, including stems, are suitable as an index to size (and to some extent weight) of plants or plant shoots. Hickey (1961) reported a curvilinear relation of basal diameter and compressed crown diameter to yield. Size of plants (indicated by diameter) may be related to area herbage yield if plant numbers remain fairly stable. By the same token, increased plant size accompanied by fewer plants may result in less yield.

Numbers.—The number of plants may be related to yield if other factors not measured do not change, or if they do, they vary in constant and predictable ways. This relationship may exist in some vegetation types so as to permit reliance on a simple tally of numbers.

Other methods.—The capacitance meter (Fletcher and Robinson 1956) determines the ratio of capacitance with herbage between condenser plates to capacitance with air between the plates. Air has a low dielectric-constant, and water in herbage has a high constant. With additional information on the degree of dryness of plants. a good relation with the yield is obtained. This method has the advantages of speed of measurement (e.g., 1 minute per "plot") and sampling all the material of a plot but leaving it undisturbed. It could no doubt be useful if worked into a double-sampling procedure.

Combination of Direct and Indirect Methods

The desirable qualities of a weight method and the speed of an indirect measurement can be combined. For example, clipped plots and foliar composition can be used together. Estimates of total yield by clipping have served a useful purpose in range grazing studies, but costs can be excessive when a study requires hand separation of material into component species and groups of species. By observing first hits on herbage by inclined pins, an estimate of species composition may be made at considerably less expense than through hand sorting (Levy and Madden 1933). This estimate of foliar composition is often surprisingly similar to actual weight composition (table 2) and with optimum conditions of herbage parts, orientation, and angle of the inclined pin, the two estimates are essentially the same (Wilson 1960). When needed, correction terms may be developed by actually sorting and weighing species from some clipped plots to compare with foliar composition (Arny and Schmid 1942; Sprague and Myers 1945; Van Keuren and Ahlgren 1957). Correction terms may not apply from year to year or from site to site if changes occur in the nature or from of the individual plant species (tables 2 and 3).

TABLE 2.—*Comparison of foliar composition (by inclined pins) and actual weight composition (by clipped and separated square-foot plots) for 2 years, San Joaquin Experimental Range, Calif.*

Species	1958 composition		1961 composition	
	Foliar	Weight	Foliar	Weight
	Percent	*Percent*	*Percent*	*Percent*
Bromus mollis	32. 5	33. 4	23. 6	18. 3
B. rigidus	4. 2	9. 7	12. 5	13. 0
All grass	54. 0	63. 9	53. 7	46. 5
Erodium spp	22. 0	15. 3	36. 9	45. 3
Other broadleaves	21. 9	16. 6	9. 0	8. 0

APPLICATION FOR METHODS

Efficient use of a research budget is an important reason for objectively considering the kind of data to be collected, methods to be employed, types of analyses to be used, and ultimate interpretation and publication. Information collected by inappropriate methods is often useless.

Sometimes interest lies in knowing only how much herbage an area is producing under grazing treatment, range improvement, or weather impact (Bentley and Talbot 1951). These may be considered as "gross" type measurements for which total yield from clipped or estimated plots will suffice (table 4).

If other questions arise, such as how treatment changes the species components of yield, then more effort must go into the clipped or estimated plot in the way of separations or other refinements. An example would be a combination of actual plot yields and estimates of weight by species (table 4).

Other methods are appropriate for indicating how increases in yield develop. For instance, direct appraisal of shoots can provide useful information on treatment-caused changes in the weight character of individual plants.

TABLE 3.—*Divergence in correction terms (K), coefficients of variation (CV), and sample size (N) for development of relation between foliar composition and weight composition, San Joaquin Experimental Range, Calif., 1961*

Species or groups	Range sites								
	Swale			Open rolling			Rocky, brushy, rolling (south slope)		
	K [1]	CV	N [2]	K [1]	CV	N [2]	K [1]	CV	N [2]
Bromus mollis	0.965	0.043	134	1.019	0.063	142	0.974	0.086	185
B. rigidus	1.264	.069	215	1.268	.082	185	1.412	.131	283
All grass	1.014	.024	74	.973	.031	71	.970	.051	109
Erodium spp	1.053	.029	91	1.182	.035	79	1.280	.041	89
Secondary broadleaves	.747	.128	396	.619	.096	218	.570	.081	173

[1] K is a ratio: $\frac{\text{weight composition}}{\text{foliar composition}}$.

[2] N is the number of plots that need to be sorted so that CV is within 10 percent of K.

TABLE 4.—*Effect of fertilizer on range herbage yield by a simple total yield method compared with a more refined species component method at the San Joaquin Experimental Range, Calif.*

Method	Range with no fertilizer	Species	Range with ammonium sulfate fertilizer	Increase from treatment
	Lbs./acre		*Lbs./acre*	*Percent*
Actual total weight from clipped plots	605	All	2,447	304
Estimated species weight composition	406	Grass and grasslike	1,944	379
	189	Erodium	497	163
	7	Clover	4	−43
	3	Other broadleaves	2	−33
Total	605	All	2,447	304

Livestock respond to herbage yield on both total and species component bases (Green et al. 1958; Wagnon et al. 1958). This response may be most obvious for live-weight increase on a unit-area basis and less obvious in the response of individual animals. In grazing intensity studies, herbage yield and resultant available forage per animal are usually reflected in animal performance (Reed and Peterson 1961; Wagnon 1959). In a study at the San Joaquin Experimental Range, range fertilization sometimes caused no increase in the rate of gain of individual steers, but increased herbage yields and more grazing resulted in substantially greater gain per acre. In other cases, neither rate of gain nor gain per unit area were influenced by change in yield caused by fertilizer treatment (Woolfolk and Duncan 1962).

Grazing use, expressed in animal days of grazing per unit area, is well related to herbage yield (Bentley et al. 1958). The relation is best if "palatable" herbage yields are used so as to exclude those plants which are seldom grazed. Direct measures of yield are appropriate indicators of potential grazing use, and so are indirect measures if they are well related to actual weights. If an indirect method results in only a relative index of yield, it becomes difficult to make any statement concerning actual yield and resulting grazing capacity. Yield of individual species may have considerable effect on capacity, especially in seasons when some species are more susceptible to trampling and other noningestion losses. Determination of average yield for several years on specific range sites permits the determination of estimated grazing capacity of heterogeneous ranges (Bentley and Talbot 1951).

Herbage yield is often a reflection of the weather. It seldom is a result of one factor, such as total precipitation, and is usually affected by

many different factors (Bentley and Buttery 1957). Results of the weather year can be mistaken for treatment-caused changes; therefore, it is usually imperative to keep weather records, replicate the treatment, and repeat the treatment more than 1 year.

SHORTCOMINGS AND IMPROVEMENT IN METHODS

The question of just what is lacking in present methods can be answered by examining current or completed studies. Much of the dissatisfaction with methods of obtaining yield are closely associated with the specific method or the way in which it is used. Sometimes these shortcomings do not become apparent until we find that yields are unrelated to animal responses or other primary end product. Often this is doubly disconcerting because the observer or data collector could see plainly the response that was being measured. Some of the following may have happened.

Data of submarginal precision collected.—An example would be to report species yields when only total yield was adequately sampled. If objectives call for study of species yields, then methods with enough precision at the species level must be used.

Inadequate standards established.—Definitions of such items as clipping height, species identification, palatable herbage, and height measurement must be very clearly stated and consistently followed. The plea for standardization of methods acquires increased importance when comparing results of studies in different range areas. The need for standardization is most urgent in longtime studies involving changes through time.

Sampling on grazed ranges.—One of the big difficulties in determining yields is that estimates often must be taken on grazed ranges. Cages are commonly used, but the cost is often prohibitive. Some procedures use direct measurement of weight on grazed ranges with estimates made of the amount of herbage removed. The chance for inaccuracy in this type of method may be great. The use of "ungrazed" plant-shoot weights (times density) may be a solution, although it assumes ungrazed shoots represent the same size of shoots that have been grazed. This may be true under situations of light use or similar palatability of all plants, but in many cases it may not be a valid assumption.

Time-cost problems.—Present methods often do not fit well within the amount of money allotted for studies. Since labor is so costly it becomes a time-cost problem. Improvements in methods are extremely important but *not* solely for cutting the workload on one project so that another can be started. More times than not, any savings through improved methods are better invested in getting better information from the same study. Some ways to help alleviate this time-cost squeeze are as follows:

1. Mobilize trained observers in enough numbers to do the job quickly so as to preclude an appreciable change in the plant attribute. At the San Joaquin Experimental Range, four men at most are available on the ground for the May "peak of production" sampling. The field job requires 20 man-weeks, or 5 weeks for the 4-man crew. By bringing in men from Berkeley and Susanville, a 12-man crew does the work in 2 weeks. Travel expense makes the quicker job more costly, but the added expense is offset by increased value of the data. Differences between the two lengths of sampling season could mean the difference between a 6-percent and a 34-percent change in actual herbage yields (Ratliff and Heady 1962).
2. Use unskilled labor to handle simple tasks. One advantage of complete plot harvest is that little experience or training is needed.
3. Strive for the development and improvement of methods so that as new studies are started, better techniques will be available. When yields are of major concern, more use should be made of direct measurements, whether by actual weight or visual estimate. Relations between other plant characters (indirect methods) and herbage yield are so changeable with seasons, sites, treatments, and years that their value is questionable. However, if the speed of an indirect method can be combined with the accuracy and control of direct weight estimation, such plant characteristics as height and cover may have great value.

Past work on a given range type is one source that often provides usable information on methods. Data from current research projects continually provide more data with methods implications. These data can often be analyzed concurrently along with regular study analyses. The researcher should be aware of the possibility of such information, as data are scheduled for automatic data processing. Finally, it is wise to plan independently functioning methods research, be it for improvement of the old or development of the new. This should proceed independently of current studies so that primary research studies do not fail or falter either because of, or for lack of, methods research.

MEASUREMENT OF PLANT COVER—BASAL, CROWN, LEAF AREA

Selar S. Hutchings and Charles P. Pase

Beginning about 1900, scientists studying and describing plant communities began to measure and evaluate the vegetal mantle in quantitative terms. A first step in an objective approach was the recognition of plant cover and plant numbers as important attributes of plant communities.

In 1905 Clements wrote, "While the number of plants per quadrat gives a much better idea of relative importance of a species, than the . . . terms, abundance, common, rare, etc. . . . The part which a species plays in giving character to vegetation . . . can be determined only by taking into account the space it occupies as well as its abundance. . . ." Thus the general concept of cover was developed.

DEFINITION OF COVER

Ground cover can be defined simply as the proportion of the ground covered or occupied by vegetation, rocks, litter, or any other material we wish to evaluate. Although a general definition is simple, the term "cover" has numerous connotations and is qualified by material characteristics of the vegetation and site. Some of the many qualifying terms are given in "Forestry Terminology" published by the Society of American Foresters in 1958, and include crown cover, forest cover, ground cover, range plant cover, vegetation cover, and others. Other authors refer to cover as "density" (Carpenter 1956; Dayton 1931).

In forestry and in many range studies, plant cover is considered to be the gross crown spread regardless of the size of "the normal or natural" openings in crowns. In some studies, the allowable size of crown openings has been prescribed, such as 4 inches, 2 inches, 1 inch, or for chart quadrats, three-fourths of an inch. Some authors have expressed cover in a single plane, i.e., the shadow cast on the ground when light was vertical or near vertical. Others recognize layers of vegetation, measuring, or evaluating each species individually. In early range surveys, plant foliage cover was visualized as standing at a 60° angle to the ground, and the plant was ocularly reduced or compacted to eliminate the foliar openings. In other studies, plant cover has been estimated or measured on "normal vegetation growth forms" but reduced to compensate for foliar openings.

Plant cover has been estimated as foliage cover: at a specified phenological stage, at various levels of stubble height following grazing, at 1 inch above the ground surface, and at ground surface.

As we can see, the term "plant cover" is an ill-defined attribute, and concepts are numerous. The indefinite vacillating approach to cover concepts is a major deterrent to development of any effective, reliable method of measuring cover. This paper deals only with measurement of plant cover or plant area.

WHY PLANT COVER IS MEASURED OR ESTIMATED

Plant cover and composition are used to describe vegetation and to measure effects of fire, drought, logging, seeding, grazing, trampling, and many other ecological factors. In early range surveys [1] cover estimates were used to characterize the vegetation and evaluate grazing capacities of specified areas.

Plant cover is also used to evaluate the protective influence of plants, i.e., shading, protection of soil from rain impact, and control of soil movement or erosion. In many studies, it is used for estimating herbage yields and composition of species.

RELATIVE EFFICIENCY OF TECHNIQUES FOR MEASURING PLANT COVER

Plant area can be either measured or estimated. Measured values are subject to sampling error, while estimates are subject to both personal error and sampling error. Both personal estimates and measured values may contain bias. In personal estimates, bias may occur voluntarily or involuntarily and may be consistent or fluctuating. Such bias often affects the sampling error.

Numerous methods of sampling plant cover have been described and compared by many writers (Brown 1954; Greig-Smith 1957; Holscher 1959; Grelen 1959; Larson 1959; Parker and Harris 1959; Ursic and McClurkin 1959; Rich 1959; Avery 1959; and Goodall 1952, 1953).

Since the general literature has been well reviewed previously, this paper deals primarily with evaluation of sampling *efficiency* of the various methods. The literature contains far too few studies that evaluate the accuracy and efficiency of the various methods of measuring plant cover. Only a few methods have been applied to synthetic populations or to native vegetation that has been completely inventoried. In some studies, methods have been modified to meet the author's concepts and ideas regarding cover.

[1] Instructions for grazing surveys on National Forests, issued by U.S. Forest Service. 1913.

In order to eliminate replication in presentation, references that discuss or compare several methods are discussed here under the heading that the individual author seemed to stress in his publication.

Ocular Estimates

Smith (1944) showed that ocular estimates of cover varied significantly among individuals and on different days, especially when men were not trained and when no effort was made to coordinate the estimate.

Pechanec and Pickford (1937) compared the ocular estimate and weight estimate methods on two areas in southeastern Idaho. They reported less variation or error in cover estimates than in weight estimates. Coefficients of variations for actual weight, weight estimate, and cover estimates were 123, 114, and 90 percent, respectively. Weight estimates more closely followed actual yields than cover estimates. Cover estimates were less variable than weight estimates, but they were not subject to accurate check.

Costello and Klipple (1939) computed the number of samples needed to give prescribed precision for various range types using ocular estimates obtained on circular 100-square-foot plots. In the plains shortgrass, 46 to 106 samples were required to estimate plant cover within 10 percent of the mean at the 95-percent level, and in various other forage types 48 to 260 samples were required for the same precision. Different vegetal types and different parts of a single type required different sampling intensity for a given sampling precision. Little relation existed between area of type and number of plots needed to sample the type. Costello and Klipple state that stratification by range condition classes or other homogeneous units would require fewer plots for each unit to obtain the same sampling precision. Sampling accuracy was not evaluated because true cover values were not available.

Quadrat Charting

Ellison (1942) thoroughly analyzed pantograph charting and compared the charted cover with the area list and point sampling procedures. He sampled three quadrats with five observers. Chart values were generally higher (30 to 40 percent) than the area list or point values. Point estimates of cover were only slightly higher than the area list. Differences between men using the chart method were significant, and they were most marked in the quadrat composed of poorly defined areas of buffalograss (*Buchloe dactyloides*).

The chart pantograph and area list methods had the lowest coefficients of variations. Coefficients of variation for point sampling were essentially proportioned to the sample size. Precision varied significantly among quadrats. Estimates of cover or composition of individual species were much less precise than that for total cover. Ellison (1954) used overlays made from pantograph charts to show successional changes in plant cover. This provided a visual method to compare change in plant cover.

Variable Plots

Hyder and Sneva (1960) used the Bitterlich (1948) method to measure basal ground cover of bunchgrasses on sagebrush (*Artemisia* sp.) range in Oregon. Results from 10 Bitterlich plots were compared with data from eight 100-foot line intercept transects. The variable plot method gave higher readings for most species than the line intercept, but the relation was not consistent between species. These authors attributed this in part to irregularly shaped plants and plants which had partially dead crown. Apparently the two methods were not applied under the same definition or concept of cover. The line intercept method allowed for dead parts, but the variable plot did not. The variable plot method required only one-ninth as much time for equal precision in sampling. The authors concluded that forty-four 100-foot line intercept transects and 28 variable plots were needed to sample within 10 percent of the mean with 95-percent confidence.

Cooper (1957), measuring shrubs in the Southwest, also recorded higher cover values with the variable plot than the line intercept method. His variable plot data for creosotebush (*Larrea tridentata*), paloverde (*Cercidium microphyllum*), and burroweed (*Happlopappus tenuisectus*) were 102, 140, and 107 percent of that recorded by the line intercept. He did not give sampling errors or sample variability.

Line Intercept

In sampling grass-forb vegetation, Canfield (1941) used eighty-eight 50-foot line intercept transects. Two major grass species, mountain muhley (*Muhlenbergia montana*) and Arizona fescue (*Festuca arizonica*), the forbs, and total herbaceous cover were sampled with coefficients of variation of 7.3, 10.6, 12.1, and 6.5 percent. The line intercept method of measuring plant cover was tested on plains grassland by Parker and Savage (1944). They had four men make duplicate readings on eighteen 10-meter lines. Analysis of variances showed no difference in successive readings by the same man; but between men differences were significant for grasses and shrubs. Man means for grasses varied be-

tween 5.8 and 6.4 and those for shrubs 32.5 to 35.3. Differences between men were not great but they were consistent.

Whitman and Siggeirsson (1954) compared line intercept with point sampling using pins inclined at 45° on the mixed grassland vegetation in North Dakota. They made 120 line transects and took 3,000 point observations. Four line transects and 100 points were considered a sample. Point hits were recorded in two ways: (1) all aerial and basal hits and (2) basal hits only. In general, point samples gave about 50 percent higher estimate of cover than the line intercept. Total cover was 20.70, 31.91, and 31.28 for line intercepts, all hits, and basal hits only, respectively.

Percent composition computed by the three sampling procedures varied. All hits favored needleandthread grass (*Stipa comata*) while basal hits favored blue grama (*Bouteloua gracilis*). All hits and line intercept measurements gave fairly similar results. Coefficients of variation for total cover were 13, 24, and 23 percent for line intercept, all hits, and basal hits, respectively. Coefficients of variation for individual species were lowest for all hits, but species varied greatly. As expected, variability was greatest for scarce species. Whitman and Siggeirsson (1954) also report that 62 to 700 line intercept transects are required to sample the various species within 5 percent of the mean at the 68-percent level, 4,300 to 29,600 points using all hits, and 4,600 to 137,500 points using only basal hits. Fifteen line intercept transects, and 2,300 points sampled total cover with equal precision.

Schultz et al. (1961) compared the ocular estimate, line intercept, line points, 10-point frame, loop, closest individual, and the variable plot on a synthetic population composed of randomly located colored discs. The population was restricted to a single plane, i.e., no discs were allowed to overlap. Ocular estimates were made without training, and the individuals were placed in two groups: (a) range society members who had some previous experience estimating cover, and (b) high school students without previous experience.

Loops used for sampling were 0.15 cm. in diameter. Schultz et al. computed cover as 20.33 percent. Estimates of mean cover by the various methods varied from 19.66 percent to 30.96 percent. Ocular estimates, loop frequency, and closest individual gave results which had a strong positive bias. The loop frequency and closest individual techniques would be strongly influenced by plant size and plant density (numbers per unit area). This is apparent in the results. The various methods gave the following data for total cover:

	Mean	*Bias percent actual mean*	*CV*
Ocular estimate:			
Society members	27.17	134	37
High school	23.88	117	-------
Line intercept	20.85	103	20
Line points	21.69	107	18
10-frame points	20.57	101	19
Loops	25.99	128	15
Closest individual	30.96	167	69
Variable	19.66	97	14

Although the synthetic population used by Schultz et al. was made by discs of nine different sizes and colors, they did not present data on estimates of composition nor did they discuss the effect of disc size. Undoubtedly, the color of discs and background would influence ocular estimates since various colors tend to present varied optical illusions to the different estimators. Also, since no part of any disc was allowed to extend beyond the 42- by 42-inch boundary, the population was not entirely random. This arrangement also undoubtedly slightly increased the percent cover of the interior of the synthetic population. Allowing for this increased cover, the line intercept, line points, 10-frame points, and variable plot sampling gave 100, 104, 99, and 94 percent of the theoretical actual cover. Therefore, these methods seem to be essentially unbiased if properly used.

Correspondence and data [2] at the Rocky Mountain Forest and Range Experiment Station compared the line intercept and belt transects on shrubby vegetation (table 1). Line intercept data were recorded on twenty 100-foot transects. Narrow (1- by 100-feet) belt transects were used to sample abundant species, and wide (10- by 100-feet) belt transects for the less abundant species. Estimated mean values and coefficients of variation for the two methods were similar.

In general, line transects were considered slightly better than the belt transects as far as remeasurement without resetting the plots was concerned. Neither method was ideally suited for use in mixed chaparral, particularly in heavy brush. Advantages and disadvantages for each method are listed below:

(1) Line transects were slightly faster and slightly less variable between observers. Substantially fewer species and fewer observations per species were recorded. Variation between transects was high, and it was virtually impossible to reestablish exact transects in the heavy brush.

(2) The double-belt transects picked up substantially more species and more observations per species, especially on sparse plots. There was

[2] Cable, Dwight R., and Pase, Charles P. Correspondence and data from files of Rocky Mountain Forest and Range Expt. Sta. 1961.

Table 1.—*Comparison of cover on line and belt transects observed by two men, one trained (Man A) and one untrained (Man B)*

Species	Line transect			Belt transect		
	Man A	Man B	Difference B–A	Man A	Man B	Difference B–A
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Total cover	67.95	67.38	−0.57	59.82	59.16	−0.66
Shrub live oak (*Quercus turbinella*)	33.89	34.10	+.21	31.34	30.12	−1.22
Birchleaf cercocarpus (*Cercocarpus betuloides*)	12.62	11.78	−.84	9.61	9.33	−.28
Redberry buckthorn (*Rhamnus crocea*)	7.08	7.29	+.21	6.33	6.75	+.42
Sugar sumac (*Rhus ovata*)	.76	.77	+.01	.77	[1] .52	−.25
Skunkbush sumac (*R. trilobata*)	2.77	2.94	+.17	1.38	1.18	−.20
Desert ceanothus (*Ceanothus greggii*)	1.52	1.04	−.48	1.02	.95	−.07
Catclaw acacia (*Acacia greggii*)	2.86	2.56	−.30	2.90	3.05	+.15

[1] One large understory plant missed by Man B.

less variation among plots, and minor displacement of plot boundaries in reestablishment of plots had negligible influence. This method requires slightly more time, and area estimates are more subjective than those made on line transects where plant intercepts are recorded. Also there was greater variation between observers.

Twenty-four 100-foot line intercepts transects on shrub-grass ranges on the Santa Rita Experimental Range sampled crown cover of grasses and shrubs with varying precision on six range pastures.[3] Coefficients of variation for perennial grasses varied from 137 to 206 percent, and those for shrubs from 63 to 103 percent.

Eighteen 50-foot line intercept transects randomly located at Sierra Ancha Research Center measured live oak (*Quercus turbinella*) and total shrub cover with coefficients of variation of 68 and 27 percent, respectively. Samples of ten 40-foot-line intercept transects in chaparral had coefficients of variation of 20 to 60 percent.[3]

Loop Frequency

Parker and Harris (1959) report that loop and line intercept methods gave comparable results on big sagebrush (*Artemisia tridentata*) range in California. A correlation coefficient of 0.97 was obtained between the two methods. Conclusions were based on five transect lines measured by four men. Three to twenty-two 100-plot lines were needed to sample cover of various species and groups within different range condition classes. The loop frequency method was tested using four men in sampling different types.[4]

[3] Forest Service Planning Factor Handbook.

[4] Pechanec, Joseph F. Progress report on Flagtail condition and trend method study. (Typewritten.) On file at Pacific Northwest Forest and Range Expt. Sta., Portland, Oreg.

Basal area index was fairly consistent if the index exceeded 20 percent. Differences between men were significant in composition rating of open forest and in total litter and total bare ground in the sagebrush-bitterbrush type. To sample a change of 20 percent at the 5-percent level, 22 clusters of 2 transects were needed in the ponderosa pine type, 25 clusters of 2 transects in the sagebrush-bitterbrush type, and 17 to 20 clusters of 2 transects in the meadow type.

Hutchings and Holmgren (1959) compared rated and unrated ¾-inch loops on two synthetic populations composed of randomly located circles. Plant cover within the loops was rated to the nearest tenth. The circles in the two populations were ⅜-inch and 29/32-inch in diameter, respectively, and they did not overlap. Unrated loops gave strongly biased results. The bias was curvilinear and disproportionately greater for small individuals.

In comparing the line intercept, variable plot, and loop methods of sampling shrub crown cover, Kinsinger et al. (1960) sampled four areas of sagebrush and salt-desert vegetation. At each site, all shrub vegetation on an apparently uniform plot (100 by 100 feet) was measured and total crown cover computed (table 2).

In this study, plots and lines were systematically located and were associated to a minor degree because of method of location. Estimates of cover obtained by the line intercept were similar to the 100-percent tally, but those from the variable plots were greater. Data obtained by using the ¾-inch loop varied with site and showed a distinct positive bias, especially for the young sparse sagebrush stands. Coefficients of variation were about equal for the loop and line intercept methods, but those for the variable plots were much lower.

TABLE 2.—*Comparison of results obtained by 3 methods of sampling shrub crown cover*

Method	Mature big sagebrush		Sparse, young sagebrush		Shadscale (*Atriplex confertifolia*)		Winterfat (*Eurotia lanata*)	
	Mean	CV	Mean	CV	Mean	CV	Mean	CV
Line intercept	4.1	78	20.6	36	13.6	72	13.9	30
Variable plot	5.0	13	23.4	20	13.8	8	20.7	9
Loop ¾-inch	4.9	76	27.3	35	16.0	71	21.8	42
Actual	4.1		20.9		10.8		18.8	

Point Sampling

Point sampling was critically reviewed by Goodall (1952). He concluded that the point sampling provided reliable data for analyzing vegetal types.

Theoretically, points have no dimension, and point sampling is based on that assumption. Actually, points used in vegetation sampling are made of pins of different sizes and, although sharpened, they still have a certain thickness. The thicker the needle or point, the greater the overestimation of cover (Goodall 1952; Winkworth 1955; Kemp and Kemp 1956; Johnston 1957; Hutchings and Holmgren 1959; and Wilson 1959 and 1960). Wilson (1959) gave a formula for computing the bias for pin size and pointed out that the errors associated with leaf width and length could be reduced by using tapered pins.

Originally, point sampling was accomplished by using vertically placed pins. In some studies, pins were randomly located; in others they were regularly spaced or randomized in groups. Levy (1933) used 10 pins separated 2 inches apart. Other authors have used different grouping and distribution of points. Unless two or more pins per location are used, it is impossible to estimate patchness of vegetation by comparing within-frame and between-frame variabilities.

Tinney et al. (1937) used points inclined at 45° to sample vegetation and stated that they gave more accurate results than vertical pins. It is not clear how the authors arrived at this conclusion because vertical and inclined pins gave essentially the same results. They did state that inclined pins were easier to read. Since then, many other workers have used the inclined point to sample vegetation (Henson and Hein 1941; Hein and Henson 1942; Arny and Schmidt 1942; Drew 1944; Sprague and Meyers 1945; Crocker and Tiver 1948; and Kemp and Kemp 1956).

Drew (1944) compared the point sampling with the count-list and weight-list methods to evaluate yield and composition of pasture lands. He used two procedures for point sampling: (a) recording only first species hit and (b) total of all hits on vegetation irrespective of whether the same plant or different plants were hit more than once. The area sampled had more than 98 percent foliage cover. Foliage composition was measured by vertical and 45° angle pins. Some results of this study are summarized in table 3.

TABLE 3.—*Pasture composition as measured by point sampling and coefficients of variations (from Drew 1944)*

Point sampling	Lespedeza				Grasses			
	July		August		July		August	
	Mean	*CV*	*Mean*	*CV*	*Mean*	*CV*	*Mean*	*CV*
VERTICAL PINS								
First hits	58.6	26	50.5	29	40.0	34	50.0	29
All hits	58.9	21	64.2	16	38.3	32	35.8	29
45° PINS								
First hits	55.5	30	42.5	48	40.3	42	57.0	35
All hits	62.1	16	60.2	23	34.7	29	40.0	33
Actual	64.1	15	59.0	19	33.4	29	40.3	28

All hits gave higher percent composition for lespedeza and less for grasses than that obtained by hand separation and weighing. In most samples the 45° pins gave less percent composition to lespedeza and more to grasses than the actual weights. Coefficients of variation were less for all hits than for the first hits, and they were generally higher for grasses than for lespedeza.

Crocker and Tiver (1948) in sampling grasslands in South Australia found that 200 point samples were sufficient for measuring dominants, and 300 to 400 points gave reliable information on dominants and fairly good appraisal of some less important species. Two things affected variability of their results, the relative cover and the distribution of species. Strong aggregated species had high variability. This could be overcome or reduced by taking samples at more locations using fewer pins per location.

Winkworth (1955) discussed theoretical relation of vertical and inclined pins in measuring foliage cover of vegetation and pointed out the effect of leaf or foliage angle on results. By comparing data from 100 vertical and inclined 10-point frames in measuring percentage cover, he found significant differences between the two methods. Cover estimated by the inclined pins was 42 percent greater than that obtained by vertical pins. Mean number of contacts per pin was 4.83 and 3.58 for vertical and inclined pins, respectively. Variance for inclined pins was greater than that for vertical pins for five of the six species sampled. The extent of overlapping of vegetation differed between vertical and inclined projections, depending on foliage orientation and distribution.

Kemp and Kemp (1956) computed theoretical or expected frequency of pin contacts with vegetation and compared these with observed values obtained by Goodall (1952). Chi-square tests show a close fit.

Point contacts can also be used to evaluate plant or foliage distributions. Goodall (1952) demonstrated that if expected proportions of contacts are not constant from location to location. fewer pins per frame and more locations are needed to give good precision. Kemp and Kemp (1956) have estimated the number of locations, for differing numbers of pins per frame, that are required for a given precision (table 4). Approximately 300 locations of 5 pins (1,500 observations) gave the same precision as 200 locations of 10 pins (2,000 observations). Until time saved in making fewer observations offset the extra time needed for moving, no economic advantage was realized.

Rated loops and point sampling were compared by Cook and Box (1961). Using the ¾-inch loop they rated only the first vegetation encountered and ignored subsequent hits on shorter vegetation. This gave higher species composition values for the tall vegetation and lower values for the intermediate and short vegetation than point sampling. It also gave lower total plant cover than the point method. The point sampling applied by Cook and Box (1961) rated multiple stage cover, i.e., all vegetal layers, while the loop favored the uppermost layers of vegetation.

TABLE 4.—*Estimated number of locations, by number of pins per frame, required for a given precision (Kemp and Kemp 1956)*

Species	Number of locations required when pins per frame are—			
	10	5	2	1
Sedge (*Carex hebes*)	200	274	495	864
Tussock grass (*Poa caespitosa*)	200	288	553	994
Purple violet (*Viola betonicifolia*)	200	327	706	1,339
Mountain woodruff (*Asperula gunnii*)	200	234	337	509
Sorrel (*Rumex acetosella*)	200	287	550	986

Evans and Love (1957) describe a procedure they call the step-point method, which consists of a combination of two procedures: (1) a series of points were located by placing a pin downward at the tip of the toe at a specified number of paces, and (2) vegetal cover was ocularly rated on a 1-square-foot plot placed on the ground at every tenth sampling point. The number of plots and step-points can be varied for type and precision desired. In annual California vegetation, nine 2-man teams using 100 step-points and ten 1-square-foot plots sampled the vegetation.

	Percent	*CV*
Total cover	37.5	14.1
Composition:		
Soft chess (*Bromus mollis*)	46.9	17.9
Other annual grasses	8.4	44.0
Legumes	17.7	20.9
Broadleaf filaree (*Erodium botrys*)	12.0	22.5
Other forbs	14.0	33.6

As usual, total plant cover was measured with greater precision than composition of individual species. The sparse annual grass group had the highest coefficient of variation.

Numerous studies have been made to compare cover estimates with herbage yields. All such studies indicate need for regression corrections between total cover and weight and also to adjust the varying relations between cover and yield of individual species (VanKeuren and Ahlgren 1957a and 1957b; Davies 1931; and Hanson 1934).

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VanKeuren and Ahlgren (1957) used regression equations to correct cover estimates by inclined point to percent composition by weight. Cover estimates corrected on the basis of yield per hit compared well with actual yields and had the lowest standard deviation. Arny and Schmidt (1942) used inclined points to analyze botanical composition of pastures. They computed mean yield per hit on a series of samples and corrected estimates proportionately. Corrected estimates of cover closely approximated actual yields obtained by hand separation, although no statistical evaluation was made.

Sprague and Myers (1945) compared hand-separated yields of Kentucky bluegrass (*Poa pratensis*) and white clover (*Trifolium repens*) to estimates made by point samples. Composition of white clover by hand separation was 1.25 to 2.93 times greater than estimates obtained by point sampling. They found that the ratios between the actual and point sampling were not constant.

Cook (1960) in a regression analysis of basal area on yield of crested wheatgrass (*Agropyron desertorum*) obtained a correlation coefficient of only 0.434.

Hutchings [5] in sampling salt-desert vegetation found that herbage yield per square foot of cover of the various species varied from 12 to 887 grams; yield of most species fell between 30 and 230 grams per square foot.

Point Sampling for Leaf Area

Point sampling is useful for measuring leaf area to correlate with physiological factors related to photosynthesis. Leaf area is often preferable to weight estimates, which include inactive photosynthetic material. Many individuals have shown that leaf area is related to productivity of crops and pastures and growth rate of plants (Donald and Black 1958; Watson 1947; Brougham 1955 and 1956; and Davidson and Phillip 1956).

Wilson (1959) showed that pins inclined at different angles estimated foliage area differently. Forty-five degree angle pins underestimated erect foliage by 36 percent. Pins inclined at 32.5° from the vertical gave sampling errors within 10 percent. When sampled with pins at 13° and 52°, the leaf area index was within 2 percent of the mean. If vegetation is sampled with pins at two or more different angles, the hits on vegetation must be appropriately weighted. These weighted values are proportional to the distances the pins travel through the vegetation. Hits on foliage are often referred to as leaf area index—the area of foliage per unit area of ground.

Spatial arrangement of foliage is also important and can be measured and evaluated by recording plant and foliage contacts by horizontal layers. In using inclined pins for sampling, the point frame should be randomly located to all points of the compass.

Point sampling of foliage provides estimates of leaf area without harvesting. Sampling is more rapid than harvesting. Also, planimetering and spatial distribution of foliage can be measured and evaluated.

Other Methods

The angle order method was used to estimate plant density and computed cover by multiplying the density estimates by average crown area per plant.[6] Computed plant cover by the angle order method was similar to that obtained by the line intercept for grasses and forbs. Estimates of cover of threetip sagebrush (*Artemisia tripartita*) and other shrubs as a group by the angle order method were much higher than those from the line intercept. No critical evaluation was made of the two methods.

Aerial photos, plot photos, and electronic equipment have been used in sampling vegetal cover, but they have not been evaluated in comparative tests. Undoubtedly these methods have merit, and they may be used with other methods for sampling vegetation. For example, forest types and forest canopy have been sampled on aerial photos using points (dot templets) or lines. Lines, grids, or dots can also be used to sample cover on photos of individual plots. This would provide a permanent accurate record of vegetal cover that could be sampled or resampled and compared with data obtained from subsequent photos. These procedures have not been tested and evaluated.

EVALUATION OF METHODS

Ocular Estimates

Ocular estimating of plant cover is a rapid method; all types can be sampled, plots can be replicated, size of plot can vary to meet different conditions in vegetal types, and the plots can be permanent or temporary. However, the method has several distinct disadvantages. Concepts of cover are arbitrarily established. Coordination

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[5] Data, Intermountain Forest and Range Expt. Sta., Forest Service, Ogden, Utah.

[6] Laycock, William A. Comparison of distance measurement, line intercept, and weight-estimate methods of sampling sagebrush-grass vegetation. [Unpublished manuscript.] Files of Intermountain Forest and Range Expt. Sta., 66 pp. 1962.

of successive sampling is usually accomplished merely by "carry-over" concept of the original estimators. In field application, there is no specific method of checking estimates against actual cover. Personal errors and bias are often great and not consistent between estimators or for the same estimator during the sampling period.

Careful training, use of frames and guides, and frequent checking can reduce variability between men. Double sampling, use of point frames for training and checking estimators, and the use of regression analysis for correcting estimates may reduce bias and variability.

Quadrats, Charts, and Pantographs

Mapped plots provide a pictorial record of vegetal changes, and individual plants can be recorded and studied for changes in cover and longevity. Plots can be permanent or temporary. The method is particularly well suited to grasslands and other low vegetal types. Charting is time consuming, and personal bias is great in mapping the crowns and basal areas of plants. Variability between men is great and not consistent from location to location. Replications are possible, but time required to chart the vegetal cover limits the number of samples that can economically be taken. As with ocular estimates, there is no method for checking results with actual cover unless point samples are used as a basis for comparison.

Variable Plot

Variable plot methods are relatively rapid, simple to apply objectively, and easy to evaluate. Plots can be replicated and can be either permanent or temporary. Variable plots are especially well suited for sampling plant populations of discrete compact individuals, such as trees. They are not well suited for measuring crown cover because dead parts of the plant and openings in plant crowns are not constant and cannot be measured, and crowns are irregularly shaped. If plots are large, it is impossible to count and accurately record the various species.

Point Sampling

Point sampling has many desirable features. It permits quantitative determination of cover and species composition in terms of cover. It is usually objective, essentially unbiased, if carefully applied, and can be randomized and replicated to provide desired precision. It does not interfere with the vegetal cover. Point sampling gives accurate unbiased estimates of ground cover, especially if the vegetation is in a single plane. Individual plots are necessarily temporary because points cannot be relocated accurately. However, line points can be used to sample successively the same general location. Point sampling is particularly suitable for use in short vegetation and can be used to sample both discrete and sod-forming species. It is not well suited for measuring cover of tall shrubs nor for estimating herbage yields unless regressions are used to correct for variation in yields.

Point sampling is used effectively to measure leaf or foliage cover of herbaceous vegetation. For this purpose, inclined points and multiple hits are recorded. This provides an estimate of foliage dispersal, as well as relative foliage area for the various species. Sampling precision can be improved by multiple sampling using pins inclined at two or three different angles.

If the points or pins have dimension, cover will be overestimated. Amount of overestimation also depends on size of vegetation and of gaps in the foliage cover. Overestimation or bias is variable; therefore, a constant correction factor cannot be used for correcting estimates. Often a large number of points is needed to provide desired sampling precision.

Line Intercept

The line intercept is generally objective and relatively accurate. It can be randomized and replicated to obtain desired precision. Lines can be permanent or temporary. In speed of application, this method falls midway between chart quadrats and ocular estimates. It is particularly well suited for measuring low vegetation and is equally accurate and usable for regular and irregularly shaped plants. Subjective decisions are made by individual estimators as to size of opening which are excluded from crown measurements. A large number of samples is needed to provide desired precision.

Loop Frequency

The loop frequency method is objective, rapid, and simple to record and measure. Plots can readily be randomized and replicated. If plots are unrated, a positive variable bias associated with plant size and plot size is introduced. If the loops or plots are rated for cover, the data are essentially subject to the same errors as those discussed under ocular estimates. The data from rated plots are not markedly biased but are often more variable than frequency data. Therefore, many samples are needed to provide the desired sampling precision.

In all methods, sampling precision of total cover and that of individual species varies widely. It is impossible to measure all species, litter, bare ground, and rock with the same precision.

Several of the methods described can be effectively used to sample total cover and that of the most abundant species with reliable precision. However, the number of samples needed to provide reliable estimates of species composition or the cover of rare species becomes prohibitive in time and effort. Point and variable plot sampling are probably best suited to manipulation for increasing precision of data on secondary species. Variation in species is probably the most difficult factor to overcome in vegetal sampling.

RESEARCH NEEDS

More detailed controlled sampling tests need to be made on synthetic populations of known cover and complexity. In the past, investigators have made comparative studies of cover sampling techniques on native populations of unknown cover quantities and quality. The various methods have often been unequally applied with modification injected into the sampling. Sample procedures for the several methods tested have often been associated and not independently randomly applied. Such procedures invalidate the results and conclusions.

We should establish a servicewide project for evaluating sampling methods and procedures. All methods of measuring plant cover should be tested on synthetic populations that have varied size and shape of plants, single and multistoried vegetation, random, regular, and aggregated populations, discrete and sod-forming individuals, regularly and irregularly shaped plants, and all other variations in complexity which would likely exist naturally in plant communities. Such tests would provide us with information on both accuracy and precision of estimates for the various methods.

After tests are made on synthetic populations, the various methods should be compared on native plant populations to evaluate sampling accuracy and efficiency. Special attention needs to be applied to the development of methods for sampling shrub cover, especially taller shrubs.

THE DETERMINATION OF PLANT DENSITY

Gerald S. Strickler and Forest W. Stearns

Density, as a quantitative measure of populations, has been used for many years to study the relation and response to change of plant populations to their environment. This paper does not attempt a complete review of plant density literature but, instead, is limited to a discussion of the problems associated with the definition of density, the methods used in its determination, and some recent applications of density measures to range plant populations.

Problems relating to density and methods for its determination have been reviewed by Brown (1954), Cain and Castro (1959), Cain and Evans (1952), Cottam and Curtis (1956), Curtis and McIntosh (1950), Evans (1952), Goodall (1952a), and Greig-Smith (1957). Much of this paper is based on these studies.

DEFINITION OF DENSITY

Density as used in this paper is defined (1) as the total number of individuals in a specified area or (2) as its reciprocal, the mean area or space per individual. There are other definitions. For example, in range management literature, density frequently refers to the ground surface area covered by foliage, crown, or basal area of vegetation. Definition of density as individuals per unit area would avoid confusion in vegetation studies.

The individual and the unit area must be specified within the defining framework of density. The individual, or counting unit, is described as the aerial parts of a single root system. This description is often difficult to follow in the field because we cannot easily observe root systems. Annual species are generally pictured as single-stemmed plants easily observed at the ground surface. This is not always true. Excavation and examination of a plot area containing dense stems of an annual grass may show extreme variation in numbers of culms for each root system. What may appear to be a multiple-stemmed shrub above ground, will, upon excavation, turn out to be two or more plants with individual root systems. Many shrub species produce both multiple-stemmed and single-stemmed plants.

Defining the individual becomes more difficult when working with perennial herbaceous species which propagate vegetatively. Several methods either set arbitrary limits to rooting areas regardless of the extent of aboveground parts or set limits to aboveground parts regardless of rooting area to define the individual unit. As Brown (1954) states, these limits are arbitrary and will differ in size between classes of vegetation, and any modification made in unit definition prevents comparison with past work.

Because of these criticisms, an individual plant stem or shoot is often considered as the counting unit. There is no theoretical basis for this practice, since the shoot may not be a "natural unit" having one root system (Goodall 1952b), but with many species it may be the only practical method to use. Using a stem or shoot as the counting unit has the advantage of less variation in size than using either bunch or rhizomatous plants and may correlate more closely with other measurements, such as weight and basal cover.

The objectives of any study will determine the definition of the counting unit and also the associated area or space. The greatest difficulty occurs when the counting unit is defined as a plant, i.e., the aerial parts of one root system. At this point, knowledge of morphology and ecology of the species, coupled with a preliminary investigation of root systems, will lead to a set of ground rules for an objective judgment of what constitutes an individual. If rules become unwieldy or a plant unit is difficult to identify, such as those of dense sod, stoloniferous, or rhizomatous plant forms or in populations where all forms are intermingled, interpretation of density data will be difficult and often misleading. In such cases other population parameters such as weight or cover may prove more useful.

DETERMINING POPULATION DENSITY

Techniques for sampling population density include (1) methods using quadrats and (2) methods using distance measures.

Quadrat Methods

Quadrat methods depend upon sampling areas of fixed size. Within quadrats, numbers of individuals are either counted or estimated. Direct counting of individuals is often tedious and difficult, depending on the ease of recognition, degree of dispersal and distribution of the individuals, and the quadrat size. Where the individuals in the population are randomly distributed, the desired accuracy of the sample and the estimate of density depend primarily on the size of the sample. Size and shape of quadrats are generally limited only by efficiency and economy. However, random distribution is not characteristic of the majority of single-species populations. The exceptions are the random distributions expected and often found in mature, single-species populations occurring in pure stands (Goodall 1952a; Hutchings and Morris 1960; Basher[1]).

When the population is nonrandom, density cannot be accurately assessed by simple methods since distribution of individuals follows neither the Poisson or normal distribution series (Clapham 1936). Several theoretical distribution series have been developed for contagiously distributed populations to which plant density data have been applied. Results have been variable. Where tests of goodness of fit between observed and expected numbers of individuals for one theoretical distribution are poor, the data, when applied to a different distribution series, may show close agreement to expected numbers. Other data will not show agreement with any distribution series. This may be due to errors in identifying separate individuals (Robinson 1954) or the effect of plot size. Because of these discrepancies, there is reluctance to use theoretical distribution to obtain sample mean estimates of contagiously distributed populations.

The choice of the sample and quadrat size on which to determine density of a contagiously distributed, single-species population is not easy. If the sample is sufficiently large, sample estimates of density will usually be distributed normally about the mean. Enlarging the size of quadrat may also result in a more normal distribution of data and thus minimize variance. When densities of all species within a plant community are required, the choice is still more difficult. If reliable estimates of several major species in a plant community are needed, quadrat size should depend on the distribution of the least abundant species. Greig-Smith (1957) states that choice of quadrat size depends on the characteristics of the population being studied, the purpose or use of the density data, a consideration of minimizing the variance of the mean, reasonable symmetry of the distribution curve, edge effects, and convenience of sampling.

Estimates of individuals per quadrat are generally assigned to one of a limited number of rank or abundance classes. Such classes differ from normal qualitative abundance classes in that quantitative limits, in numbers or average spacing of the individuals, have been set for each class. Where density of all species in a plant community is desired, estimating, because of its speed, often may be the only practical procedure; however, problems of nonrandom distribution and plot size would still exist.

An indirect estimate of density can be obtained with plot frequency data by using the logarithmic relationship between density and frequency. This relationship is simple only when the population is randomly distributed and several counting units occur within the quadrat. Assuming that distribution of most biological populations is nonrandom, plot-frequency data has little use in the determination of density (Aberdeen 1958).

[1] Basher, Mustafa M. Use of mean distance between plants in determining adequate plot size. 1961. (M.S. thesis on file Utah State Univ.)

Distance Methods

Distance methods are not new, yet their extensive use in plant community analysis did not occur until the random pairs method in sampling density and other characteristics of forest trees was introduced (Cottam and Curtis 1949). Since 1950, a number of distance methods, based on the concept of mean area per individual, have been developed. Where accurate estimates of numbers are required, the distance methods can be separated into those applicable primarily to randomly distributed populations and those applicable to both randomly and nonrandomly distributed populations.

Methods for Randomly Distributed Populations

The first group includes the (1) closest individual, (2) nearest neighbor, (3) random pairs, and (4) point-centered quarter methods.

The closest individual method.—The sample is the distance between a sampling point and the nearest plant. Mean area per individual is obtained by squaring the doubled value of the mean distance (Cottam et al. 1953). It is the least accurate but simplest method for randomly distributed populations.

The nearest neighbor method.—The distance between an individual and its nearest neighbor is the sample. Where individuals are selected at random, the average of distances to nearest neighbors is multiplied by a correction value of 2.00 before squaring to obtain the mean area. This involves numbering all individuals of the population for random selection or measuring nearest neighbor distances in random quadrats within the population, both time-consuming techniques. Stratified sampling, selecting the individual nearest a randomly located point and measuring to its nearest individual, is recommended (Cottam et al. 1953). The observed distances are multiplied by a correction factor of 1.67 before squaring to obtain mean area.

The random pairs method.—This method is widely used in studies of timber stands. The usual procedure is to find the plant nearest to a randomly selected point and measure the distance to the nearest neighbor that lies outside an exclusion angle. A 180° angle of exclusion is recommended, with its vertex at the sampling point and its bisector extending through the closest plant. Mean distance is multiplied by a correction factor of 0.80 before squaring to obtain mean area (Cottam and Curtis 1956).

The point-centered quarter method.—Distances are measured from a sampling point to the nearest plant in each of four 90° sectors around the point. The average of the four measurements at all points is equal to the square of the mean area per plant. Estimates of density can then be obtained directly by squaring the reciprocal of the average mean distance per point without the use of a correction factor. Density can be determined from the average distance of the first, second, third, and fourth nearest plants at each point regardless of quarters, when the proper correction factors are applied.

Cottam and Curtis (1956) compared the sampling adequacy of these four methods applied to one artificial and three natural populations of forest trees and found all methods gave mean values of stem density (all species combined) close to actual values. The point-centered quarter method was considered superior to the others because it resulted in less variation in mean distance at points, provided more data for individual species, and was the least susceptible to subjective bias.

The closest individual, nearest neighbor, and point-centered quarter methods were evaluated and estimates compared with plant counts on pure stands of common winterfat (*Eurotia lanata* (Pursh.) Moq.) and black sagebrush (*Artemisia nova* A. Nels.) and mixed stands of these species with other desert shrubs (Hutchings and Morris 1959). Close agreement between methods was found only when species were randomly dispersed. Individuals in pure stands and all species in mixed stands were essentially random, but individuals of any one particular species in mixed stands were often strongly contagious.

The point-centered quarter method was tested on various species and species groups in the California annual grass type and the estimates of numbers compared to those obtained on quadrats of 1, 2, and 14.4 (0.1 square foot) square inches.[2] Sampling was done in three swale and two slope sites. On slope sites, estimates of numbers per square foot obtained by the point-centered quarter method were consistently lower than quadrat counts (table 1). Greater differences occurred in swale sites. Density estimates of *Erodium* species and grasslike *Carex* and *Juncus* species by the point-centered quarter method were as low as 0.3 and 2 percent, respectively, of plot counts. Such large differences in density were attributed to the contagious distribution of individual species and its effect on both distance measurements and quadrat counts. Possibly some of the differences resulted from using a shoot as the individual. Where plants are

[2] Personal correspondence with Meredith J. Morris, Rocky Mountain Forest and Range Expt. Sta., April 13, 1962.

more widely spaced than shoots within the plant, distance measurements to shoots may often result in a larger mean area per shoot and thus less density than plot counts of shoots.

TABLE 1.—*Number of plants per square foot on slope sites, California annual type, as determined by two methods* [1]

Species	Quadrat method			Point-centered quarter method, 50 points
	200 1-sq. in. quadrats	200 2-sq. in. quadrats	100 14.4-sq. in. quadrats	
Ripgut brome (*Bromus rigidus* Roth)	58.32	55.80	44.20	16.87
Soft brome (*B. mollis* L.)	51.12	45.72	43.60	13.04
Other grasses	87.12	68.40	58.20	16.62
Broadleaves	30.96	26.64	23.00	7.72

[1] Data supplied by Meredith J. Morris, Rocky Mountain Forest and Range Expt. Sta., 1962.

Methods for Randomly and Nonrandomly Distributed Populations

The second group of distance measures includes the angle-order method (Morisita 1957) and the wandering quarter method (Catana 1963). Because both methods are relatively new, the procedures in their use are more fully described.

The angle-order method.—Two unbiased estimates, $\overline{m}_1$ and $\overline{m}_2$, of the mean density, m, of the population are obtained. The method is based on the assumption that, regardless of population distribution, total population area can be divided into several small fractions within each of which individuals are distributed randomly or uniformly, and total density can then be calculated from the individual fractions.

The procedure is to position sample points ($i=1\ .\ .\ a$) randomly or regularly over the area, divide the area around each point (i) into equiangular sectors ($k=1\ .\ .\ b$), and measure the distance (r) to some nearest plant (n) in each sector (fig. 1). Morisita (1957) states the method has its most practical use when four sectors are employed at each point, and the distance to the third nearest plant in each sector is measured. An alternative in positioning sample points is to place an equal number in each of "many" equal fractions of the sample area.

The estimate $\overline{m}_1$ is obtained by using the sum of reciprocals of the squared distances in each sector of all sample points in the equation:

$$\overline{m}_1=\left[\sum_{i=1}^{a}\sum_{k=1}^{b}\frac{1}{r_{ik}^2}\right]\frac{n-1}{a}$$

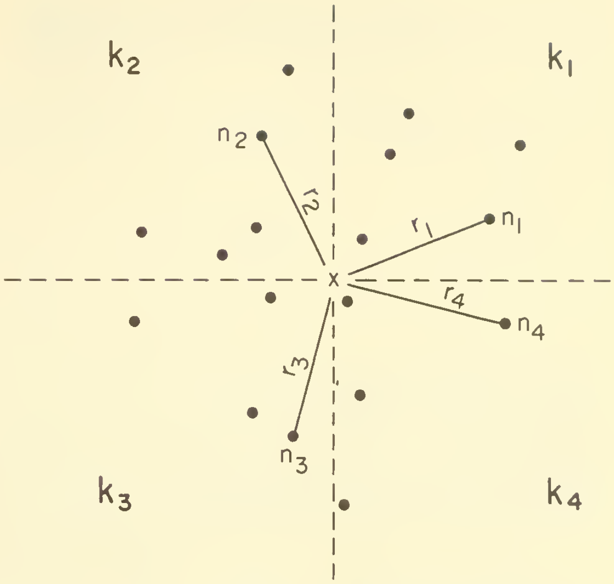

Figure 1.—Angle-order method. X is a sampling point. Dotted lines divide the area around the point into equiangular sectors (k). Heavy lines represent the measured distances (r) to the third nearest plant (n) in each sector.

To obtain $\overline{m}_2$ each distance measurement in each sector is squared, the squared values summed for each point, and the reciprocal of the sum determined. The sum of reciprocals for all points is then used in the equation:

$$\overline{m}_2=\left[\sum_{i=1}^{a}\frac{1}{\sum_{k=1}^{b}r_{ik}^2}\right]\frac{k(nk-1)}{a}$$

The estimates are compared and, if $\overline{m}_1$ is greater than $\overline{m}_2$, $\overline{m}_1/\pi$ is the estimate of density per unit area. If $\overline{m}_1$ is less than $\overline{m}_2$, the average, $\overline{m}_o$, of the two estimates is calculated, and $\overline{m}_o/\pi$ is the more accurate estimate of population density.

On artificial populations showing regular, random, and contagious distribution, Morisita (1957) obtained sample estimates of density within 0.1, 1.8, and 5.0 percent, respectively, of actual density. Both regular and random distribution of points were used.

The method has been applied to several species of the desert grass type of Arizona.[3] Estimates of density from sample points, with $n=3$ and $k=4$, were compared with those obtained by the point-centered quarter method and quadrat counts. Table 2 summarizes the results of this study. According to Morisita (1957), $\overline{m}_1/\pi$ would be the

[3] Personal correspondence with Meredith J. Morris, April 13, 1962.

more correct estimate of population density, since the estimate of $\overline{m}_1$ was higher than the estimate $\overline{m}_2$ for all species (not shown in table). However, numbers obtained by the average of the two estimates, $\overline{m}_o/\pi$, agreed more closely with quadrat counts and were considered the better estimate.[4]

TABLE 2.—*Number of plants per square foot in Arizona desert grass type as determined by three methods* [1]

Species	Methods and number of samples			
	Quadrat,[2] 100 quadrats	Point-centered quarter, 100 points	Angle-order, 100 points	
			$\frac{\overline{m}_1}{\pi}$	$\frac{\overline{m}_o}{\pi}$
Bouteloua rothrockii Vasey	0. 1338	0. 0073	0. 3024	0. 2546
Trichachne californica (Benth.) Chase	. 0988	. 0412	. 1261	. 1165
Other perennials	. 2326	. 0902	. 3589	. 2941
Annuals	5. 4919	. 9902	8. 0151	6. 9217
Prosopis juliflora velutina (Woot.) Sargent	. 0024	. 0022	. 0031	. 0028
Aplopappus tenuisectus (Greene) Blake	. 1128	. 0309	. 1455	. 1249
Opuntia spp	. 0279	. 0123	. 0304	. 0254

[1] From data supplied by Meredith J. Morris, Rocky Mountain Forest and Range Expt. Sta., 1962.
[2] Quadrat size varied by species.

Estimated numbers by either technique of the angle-order method were closer to quadrat counts than were numbers obtained by the point-centered quarter method. The one exception was density values obtained for *Prosopis*. This species was randomly distributed and, therefore, the three methods gave similar estimates of its density. The contagious distributions of the other species biased point-centered quarter estimates of their density. Quadrat counts were also biased by contagious distribution. Therefore, to evaluate the angle-order method with known population densities, total counts of two species and one species group were made in a square plot, 400 feet on a side. One hundred angle-order points were taken to sample each species with $n=3$ and $k=4$. The results showed estimated numbers per square foot to be very close to numbers determined by actual count:

Species:	*Total count* (*number per sq. ft.*)	*Angle-order method* (*number per sq. ft.*)	(*percent difference*)
Trichachne californica	0. 02205	0. 02162	−1. 5
Opuntia spp	. 006406	. 006817	6. 4
Prosopis juliflora velutina	. 002262	. 002415	6. 8

These results indicate that quite accurate estimates can be obtained by the angle-order method.

The wandering quarter method.—A sequence of measurements is taken through a population, and several analyses of these measurements are made by nonparametric methods to calculate plant density and distribution. It was devised to estimate density and distribution of individuals and clumps of individuals in aggregated populations without excess bias and to permit calculation of error involved.

Data are collected from four transects run in a predetermined compass bearing across the study area (fig. 2). A point is determined randomly for each transect, and the nearest individual within a 90° angle of inclusion around the compass bearing from this point is taken as the starting point for the distance data. A second 90° angle of inclusion is marked off with the first individual as its vertex and the compass bearing as the bisector. The distance is measured to the closest individual within this 90° angle. The same operation is continued until a set number of distances has been obtained (usually 25).

The mean for the distances in all four transects is determined. A frequency distribution of distances is constructed, and the median and modal distances are calculated:

$$\text{Median}=L+\frac{N/2-S}{f}i$$

(Peters and Van Voorhis 1940)

where L is the lower limit of the median class, N the total frequency, S the partial sum up to the median class, f the frequency in the median class, and i the width interval of the class.

$$\text{Mode}=\text{mean}-3(\text{mean-median})$$

[4] Personal correspondence with Meredith J. Morris, April 25, 1962.

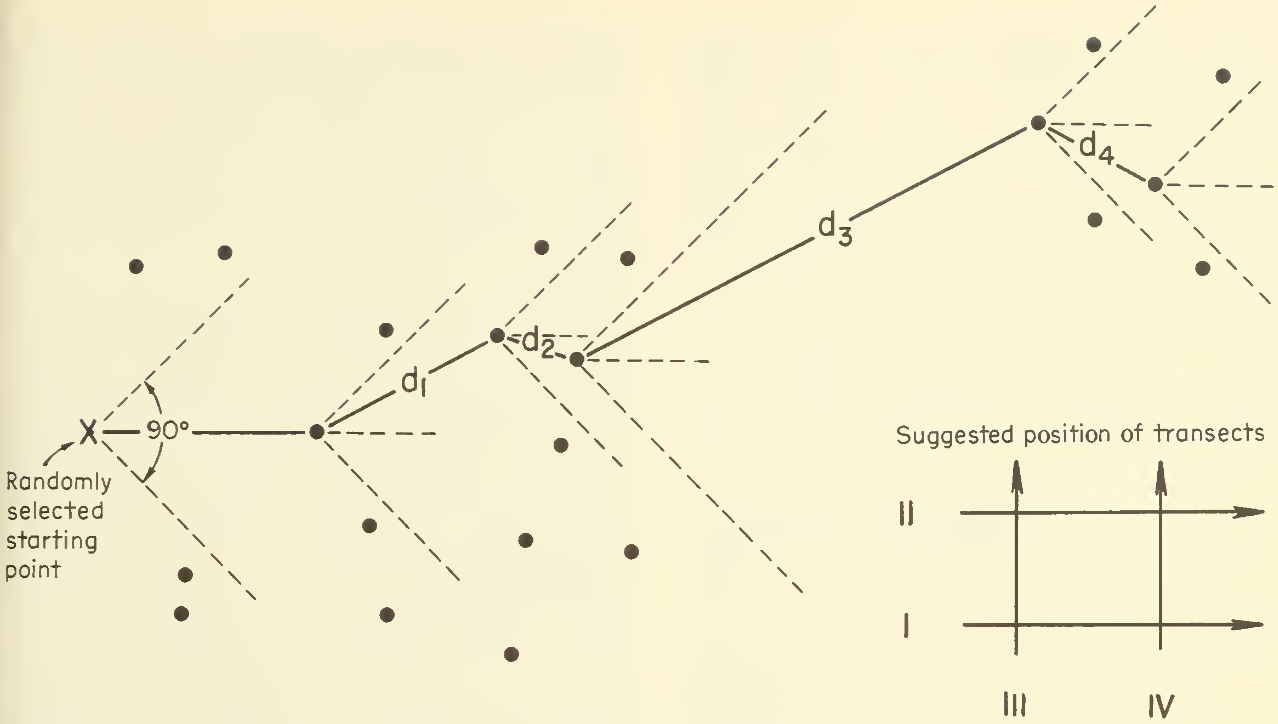

Figure 2.—The wandering quarter method. X is the randomly determined starting point for each transect. Horizontal dotted lines are the compass direction for each transect. Heavy lines are measured distances between individuals. (From: Catana, Anthony J., Jr. The wandering quarter method. 1960. Ph. D. thesis on file Univ. Wis.)

In skewed data from highly aggregated populations, the median gives a better estimate of the mode.

Next, a separation of distance measurements is made into what is termed within-clump (y) and between-clump (x) measurements. Those distances which are 3(mode) or less are designated as y distances. No separation into x and y distances will appear in a random population, for all values will be within the 3(mode) limit. In random populations and assuming the mean distance between individuals is equal to the square root of the mean area of individuals, the mean area of the individuals is determined as $MA=d^2$ where MA is the mean area of an individual in terms of d, the mean distance. Density (D) per unit of area is then calculated as A/MA.

Where a separation into x and y distances occurs, the means of these distances can be used to obtain values of three interrelated plant variables, W, C, and K, and the values used to obtain an estimate of density (fig. 3). The mean within-clump distance ($\bar{y}$) is used to determine both the mean within-clump area per individual (W), using the same method for random distributions as given above, and area of the clump (C). To obtain clump area (C), the mean within-clump distance ($\bar{y}$) is reduced to unity (all other distances are correspondingly reduced), and applying correction factors,[5] a diameter (z_1) and radius (r_1) of clumps is determined. A formula using radius (r_1) value determines the number of individuals per clump (N). Knowing N and W, the area of the clump (C) is calculated as $C=WN$.

The mean between clump distance ($\bar{x}$) is used in determining mean area of clump (K) within the population area. Assuming the clumps are circular, actual mean diameter of clump ($\bar{z}$) is calculated from the area of the clump (C). Assuming random distribution of clumps, the mean area of clump (K) is equal to the square of the sum of the mean distance between-clump peripheries ($\bar{x}$) and the mean clump diameter ($\bar{z}$). The number of clumps in the population studied is then calculated:

$$\text{Number of clumps}=\text{unit area}/K$$

and, knowing the number of individuals per clump (N), the population density is calculated as:

$$D=(\text{number of clumps})N$$

The number of between-clump distances (x) is usually small and more may be required. It is

[5] Catana, Anthony J., Jr. The wandering quarter method. 1960. (Ph. D. thesis on file Univ. Wis.)

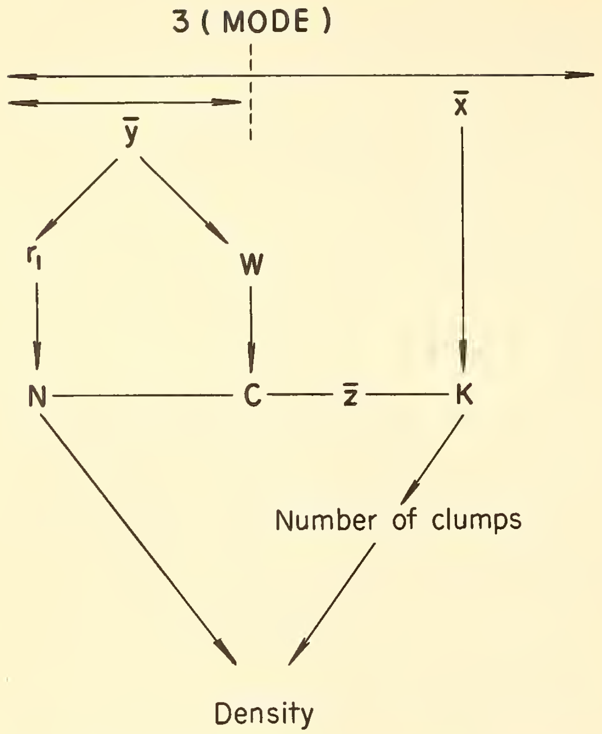

Figure 3.—Schematic diagram of procedure to obtain density per unit area in contagiously distributed populations by the wandering quarter method.

assumed that there are enough distances if the standard error is less than 10 percent of the mean ($\bar{x}$). If more than 10 percent, the number of distances needed is calculated and then obtained by running additional transects.

This technique has been applied to a number of known populations of herbs, trees, and shrubs, and to artificial populations. Density estimates proved to be very close in all cases except in random populations with abnormally large spaces lacking individuals. In this case, estimated density was too high. Estimates will be in error if distribution of clumps is other than random.

The main advantage that distance methods are considered to have over quadrat methods is efficiency in sampling for a given degree of accuracy. This may not be true for all populations. Lindsey et al. (1958) tested the efficiency of the point-centered quarter method with that of quadrat methods in a forest stand. They found that 1/10-acre plots using the rangefinder plot method (Lindsey 1956) were more efficient in obtaining density estimates of two major tree populations than the point-centered quarter method. Fifth-acre strip quadrats were also more efficient for one of these populations. Similar comparative tests in herbaceous populations would be desirable but are lacking.

Preliminary work indicates that when the only objective is estimating density, plot counts may be more efficient than some distance methods.[6] Carefully prepared study objectives plus preliminary observation of the study population will suggest whether a distance method would be more efficient than a quadrat method to obtain density estimates. The advantages and limitations of all methods should be carefully considered before a choice is made.

Distance methods are most useful when applied to one species in autecological studies. They can, however, be used to study an entire complex of species. In such studies, absolute values of species density are often not critical, and relative values are calculated for comparing species composition between plant communities and for ordination of communities. Although relative densities are valid, they are dependent on estimated density of every species used in calculation of total density. Any departure from random distribution of the total species population would have an effect on accuracy with which relative values are determined.

When using distance methods to obtain estimates of numbers of single species or species groups within dense communities, considerable time may be spent in searching for the desired individual.[7] This difficulty is compounded when other species are present which are similar in morphological characteristics to the one being studied. In the angle-order method where the third or more distant plant from the point is required, the difficulty in locating individuals may become insurmountable.

USES OF PLANT DENSITY

Distribution of Populations

Plant populations are either regularly, randomly, or contagiously distributed in time and space. Density data can be used to show if a population is distributed at random or how different from random.

The discrepancy between observed quadrat data and calculated data from the Poisson distribution has led to a variety of quadrat methods which determine nonrandomness. Greig-Smith (1957) gives a detailed review of eight quadrat methods and concludes that the modified form of David and Moore's (1954) Index of Clumping is the preferred measure.

Four methods of determining departure from randomness based on distance measures have

[6] Personal correspondence with Meredith J. Morris, April 13, 1962.

[7] Personal correspondence with J. N. Reppert, Pacific Southwest Forest and Range Expt. Sta., Jan. 25, 1962.

been tested on artificial populations by Cottam et al. (1957). Pielou (1959) developed an index, with corrections by Mountford (1961), using distance measures in populations of known density. Morisita (1957) used a third estimate of the population density $\overline{m}_3$ to determine nonrandomness in which the distribution is contagious, random, or regular if $\overline{m}_3$ is respectively greater than, less than, or equal to the calculated average density, $\overline{m}_0$.

Indices of nonrandomness measured by distance methods have an advantage over those determined by quadrat techniques in that they are not influenced by quadrat size. Indices developed from quadrats have meaning only in relation to quadrat size. In the selection of a distance method, time requirements and simplicity of technique should be considered.

Indices of nonrandomness serve largely to indicate what kind of distribution pattern exists, if any, and what factor may be controlling the distribution of individuals. Interest in nonrandom or other distribution patterns lies in the ecological implications of such findings (Greig-Smith 1957; Hopkins 1954).

The factors controlling distribution can sometimes be interpreted by fitting density data to one of several theoretical distributions. Often the fit is accidental and the underlying assumptions and the interpretations of the theoretical distribution obscure (Kemp 1960). The controlling factors may differ between species or even for one species within time and space. No mathematical formula is valid for all cases (Hairston 1959).

Greig-Smith (1952) introduced a quadrat density technique for studying population distribution patterns and the factors involved. Briefly, the method entails recording of a quantitative measure of the population (density, cover, or frequency) in grids or transects of contiguous quadrats. In the analysis, data from the quadrats, or "basic units," are grouped into blocks of increasing size. Total variance between basic units is then apportioned into amounts derived from the differences within blocks of two, between blocks of two units within blocks of four, etc. When this apportioned variance is plotted against block size, the pattern of distribution in terms of block size is reflected in peaks on the graph. Environmental factors are measured in the same manner, and where peaks are similar to those graphed for density measurements, any relationship between the distribution pattern and the environmental factor or factors can be determined through correlation analysis.

Use of this technique, with cover or frequency as the parameter measured, has shown population distribution patterns to be correlated with soil depth (Kershaw 1957), morphology of the species (Greig-Smith 1957), and aeration (Anderson 1961). Changes in peaks on the variance-block size graph have been shown to occur as a result of grazing by sheep (Anderson 1961) and indicate the possibilities of this method in studies of plant distribution as affected by livestock and big-game grazing. When density is the parameter chosen, the quadrat size used should result in an average of one individual per quadrat.

Little use has been made of distance measures to study the relation of environmental factors to distribution of herbaceous plant populations; other studies indicate some possibilities. Cottam et al. (1957) studied the effects of changes in three plant variables on the aggregation of artificial populations. These variables, K, C, and W, were defined in the discussion of Catana's [8] wandering quarter method.

Pielou (1960) studied populations of ponderosa pine (*Pinus ponderosa* Dougl.) and found a positive correlation between nearest neighbor distances and the sum of the trunk circumferences of the two neighboring plants which was assumed to reflect the sizes of the root system. She concluded that the correlation indicated individual trees were competing with each other for available space; the competition being, in part, responsible for the aggregation of the population.

Cooper (1961) studied ponderosa pine distribution in Arizona and found no consistent trends in the correlation of trunk circumference of each tree with distance between trees, although significant competition among trees was shown to be operating. He concluded that the irregular (or nonrandom) distribution pattern resulted from shade, harsh environment, and periodic fire.

Box (1961) used distance measures to determine density of 10 woody plants on 4 range plant communities in Texas. He found brush density in some communities to be significantly correlated with one or more soil properties, such as potassium, chloride, soluble salt content, or percentage micropores.

Classification of Populations

Classification of plant populations for range management purposes provides a base from which effects of grazing can be evaluated. Generally, the base is established as a maximum or desired potential value. Any departure from the base is assumed to be a result of grazing, and the plant community classified accordingly.

Plant density has had less use than other quantitative measures in determining effects of grazing. Plant density data from quadrats has been used to advantage where the area of treatment

[8] Catana, Anthony J., Jr. The wandering quarter method. 1960. (Ph.D. thesis on file Univ. Wis.)

was small, the population consisted of only one or a few species, the individuals were easily recognized, and the change in density was large. These conditions are often met in clipping experiments which simulate grazing, or less frequently, in studies on the effect of large differences in grazing intensity on specific plants (Tomanek and Albertson 1953; Houston 1961). Often, the area of treatment is large, and our interest is in the highly variable density change and distribution of many or all species in a community. With these conditions, collection of quadrat density data is laborious, and, although changes in density may be great, the extreme variability in density between quadrats may render changes nonsignificant (Branson and Payne 1958; Marquiss and Lang 1959).

Recently, two techniques using estimates of density by both quadrat and distance methods have been used in classifying and determining changes in grazed plant populations. Both techniques, introduced by Dix (1959, 1961), use relative density. Some discussion of their advantages and limitations appears opportune.

In the quadrat method, Dix (1959) sampled 24 pairs of ungrazed and grazed prairie stands to obtain a classification or "grazing gradient" of stands. From quadrat frequency data, absolute density and relative density were determined for each species. Absolute densities were used to develop a "grazing susceptibility number" for each species based on the differences in species density between the ungrazed and grazed stands. The products of the grazing susceptibility number and the relative density for each species in each stand were summed to give the stand index number. The stands were then positioned along the grazing gradient.

When density of selected species was plotted against the grazing gradient, Dix found that the changes in density conformed with known behavior under grazing or other disturbances. He concluded the method had certain advantages in classifying or ordinating stand condition and, once the classification was established, other grazed stands could be positioned along the grazing gradient.

The method has a good feature. Classification is not based or dependent upon a definite value of climax composition. Although the site is defined, no set values of individual species composition, such as potential values, are assumed. Stand classification is dependent only upon the total sum of calculated values. The method appears to alleviate the ever-present difficulty of establishing potential values for species composition and their changed values in a grazing classification for a given site.

The method has disadvantages. Before adapting it to other areas and environments, a large number of pairs of ungrazed and grazed stands on similar sites is required to arrive at a meaningful grazing susceptibility number. Finding ungrazed or relict areas is always difficult. A second consideration, stated by Dix, is that the grazing susceptibility numbers apply "only within the framework of their derivation." Any change in the density of a species as a result of change or difference in grazing pressure would result in a different initial grazing susceptibility number.

The second technique introduced by Dix (1961) utilizes the point-centered quarter method to express species composition in herbaceous communities. A surveyor's pin is placed in the soil at predetermined points along a traverse line. At each point the area surrounding the pin is divided into quarters, and the distance from the pin to the nearest plant shoot in each quarter is measured. Total shoot density is calculated disregarding individual species. Using each point as a plot, the relative frequency and relative density of each species is calculated. In a manner similar to that of Curtis and McIntosh (1951), relative density and relative frequency are then summed to form an importance value expressing species composition. Absolute species densities are calculated for each species; these values are the product of the relative density of the species and total population density per unit area. The importance values and absolute densities of individual species are used to compare populations and to evaluate effects of treatment.

Dix (1961) tested this method on three grassland stands in western North Dakota and concluded that the technique not only provided a rapid means of obtaining species composition but appeared efficient in "detecting slight differences between closely related stands or vegetal changes in time within a stand due to treatment or climatic shift."

Dix's method was tested in mountain grasslands in eastern Oregon coincident with a study of optimum plot size for trend analysis.[9] The closest individual method was used to obtain an array of 150 distances for each of the two or three most abundant species in paired ungrazed and grazed stands. Density per square foot for these species was calculated. Using the same sampling points, the point-centered quarter method was applied to the total species population; and relative density, absolute density per square foot, and importance values were calculated for the desired species.

Importance values, relative density, and absolute density did not reflect the differences between grazed and ungrazed stands as shown by cover

[9] Data on file at the La Grande, Oreg., field office of the Pacific Northwest Forest and Range Expt. Sta., U.S. Forest Service.

and herbage weight data. For example, in a 10-acre relict stand and its grazed counterpart, these calculated values for bearded bluebunch wheatgrass (*Agropyron spicatum* (Pursh.) Scribn. and Sm.) and Sandberg bluegrass (*Poa secunda* Presl.) did not reflect the relatively large differences in clipped weight nor the differences in absolute density determined by the closest individual method (table 3). Because the absolute density values determined by the closest individual method were calculated as single-species populations, they were considered to be more realistic of differences in plant numbers between paired stands than absolute densities derived from relative densities obtained by the point-centered quarter method.

Relative densities and especially relative frequencies used to determine importance values for major species were strongly influenced by densities of secondary and associated species and total population density. Only when total population densities were similar in the paired stands did values calculated by the point-centered quarter method reflect changes in density, cover, and weight. It was concluded that for the population studied, importance values and absolute density values calculated by the point-centered quarter method might give a relative measure of the contribution of numbers of each species *within a stand*, but would not detect even large differences in numbers or other characteristics between stands as a result of grazing treatment.

TABLE 3.—*Importance values, densities, and clipped weights of two major grasses in two plant communities in eastern Oregon*

Species and plant community	Point-centered quarter method			Closest individual method; absolute density (per square foot)	Clipped weight (air-dry)
	Importance value	Relative density	Absolute density (per square foot)		
Agropyron spicatum:	*Percent*	*Percent*	*Number*	*Number*	*Pounds per acre*
Relict	65	33.5	15.104	5.000	670
Grazed	60	29.7	13.750	1.667	305
Poa secunda:					
Relict	90	48.6	23.289	11.042	100
Grazed	103	56.3	26.146	6.562	70

This study places doubt on the use of relative density and relative frequency to show change in herbaceous communities. Relative density of individual species, by either quadrat or distance methods, is influenced by the density of all species. Frequency of individual species is influenced by quadrat size and by the density of other species when using distance methods. When frequencies are summed to obtain relative frequency values for each species, these values are strongly influenced by the contribution to total frequency by all other species. Considerable bias can be expected in summing relative density and relative frequency to obtain a value reflecting species composition.

RESEARCH NEEDS

Investigators in range and wildlife habitat research should acquaint themselves with the advantages and limitations of density data and the methods used to determine density. Distance methods have lessened considerably the problems associated with determining density by quadrat methods and, simultaneously, have caused increased interest in the use of density to solve research problems. We must, however, thoroughly test the sampling adequacy of the distance methods before they are indiscriminately applied in research or management of range plant populations.

We should develop and apply, where applicable, new density measures to further the knowledge of the ecology of plant species and communities and their response to livestock and game use. Examples of studies which show promise in this regard are those on the influence of plant density on solar energy conversion of individual species populations (Kamel 1959), on the growth and production of individual plants and plant communities with regard to varying environmental conditions with time (Kira et al. 1953, 1954), on the pattern and aggregation of clumps (Agnew 1961; Cottam et al. 1957), and on the segregation and symmetry of populations (Pielou 1961). Potential plant density of range sites,

particularly potential densities of the dominant species, should be investigated. Recent studies indicate such information has value in range condition classification or for improving quadrat techniques presently being used for this purpose.[10]

THE USE OF RATING OR RANKING IN VEGETATION MEASUREMENT

Meredith J. Morris

Ratings and rankings of plant attributes have been developed and used for many years by grassland workers, particularly in extensive surveys and plant sociological studies. In this discussion, a rating is defined as the scale value obtained when some attribute or property of vegetation is scored or otherwise rated by an individual or group of individuals. This rating or scoring is decided upon by judgment. Ranking is defined as the ordering of observations with respect to size or magnitude of some characteristic. For example, if m objects are arranged in order of magnitude and the integers 1, 2, . . . , m assigned to these objects, then ranks of 1 to m will be obtained. Ranks may be obtained directly as original data or, for some reason, from the replacement of quantitative numerical observations.

RATING OR SCORING

Density, aerial cover, basal area, and weight are examples of plant attributes that have been rated or scored. The ratings have been expressed in terms of various types of scales, from about five classes on up to a 100-point scale (percent) and even to an almost continuous type of scale, such as visual estimates of herbage weights on a series of plots.

Brown (1954) reviewed many of the rating systems used by grassland workers. Much of the early work involved ratings of only a few classes. These were used in extensive surveys, the information obtained being used only for descriptive purposes. The ratings were extremely subjective, and the information derived was vague since no statistical methods had been developed to analyze the scores or ratings.

When ratings with fairly large numbers of classes were used, normality was often assumed and the results were analyzed by normal distribution methods. In most cases, the assumption of normality was probably valid. Where such an assumption cannot be made, however, as in certain cases involving percentage data, an appropriate transformation may often be found that will satisfy the normality assumption on the transformed scale. Bartlett (1947) discussed this problem in some detail and gave appropriate transformations for several examples.

A scoring technique that is somewhat different from those usually used in range work was developed and tested by Schmautz [1] in Montana. Briefly, he visually estimated total herbage weight of four plots in a cluster as percentages of a fifth, or base plot, which was also contained in the cluster. Weights of individual species or vegetative classes in each of the four plots were also estimated as percentages of the base plot. The base plot was then clipped and weighed. Herbage weight in the four plots was then calculated by converting percent weight and percent composition into weight units, such as grams from the actual weights on the base plot. Of course, the base plot could have been estimated visually into absolute weight units before it was clipped; the method would then be a type of double sampling. Schmautz hypothesized, however, that it is easier to estimate relative production than absolute production, so double sampling was not used.

Schmautz found that observers tended to be erratic in their estimates, particularly for extreme values and more so for grasses than for forbs or shrubs. Relative shrub weights were estimated most accurately.

The method shows enough promise to warrant further investigation into the problems involved and possible improvements.

RANKING

Kruskal and Wallis (1952) have summarized some of the advantages of using ranks as follows:

"(1) The calculations are simplified. Most of the labor when using ranks is in making the ranking itself, and shortcuts can be devised for this. . . .

"(2) Only very general assumptions are made about the kind of distributions from which the observations come. . . .

"(3) Data available only in ordinal form may often be used.

[10] Basher, Mustafa M. Use of mean distance between plants in determining adequate plot size. 1961. (M.S. thesis on file Utah State Univ.)

[1] Schmautz, J. E. Test of a range sampling method—percent weight production. 1961. (Unpublished report on file at Intermountain Forest & Range Expt. Sta., U.S. Forest Serv., Ogden, Utah.)

"(4) When the assumptions of the usual test procedure are too far from reality, not only is there a problem of distribution theory if the usual test is used, but it is possible that the usual test may not have as good a chance as a rank test of detecting the kinds of differences of real interest."

There are also some disadvantages in using ranks:

1. The quantitative nature of differences in observations with adjacent ranks is ignored, thus causing a possible loss in efficiency. This loss is sometimes offset by the fact that the use of ranks reduces the experimental and analysis times so that larger samples, which will make up for the loss in efficiency, may often be used (Bradley 1955).
2. Some ranking techniques are essentially limited to testing hypotheses and are relatively useless in estimating the size of treatment differences.
3. Ranking systems do not permit ties. The observer is forced to assign a difference even though he can detect none.

It has been recommended by some statisticians that ranks be transformed to scores for ordinal data as given by Fisher and Yates (1949 in table XX) before standard analysis of variance techniques are used (see Bartlett 1947). Rank analogs of "t" tests for two independent samples, for two paired samples, and for a single sample are available. Rank analogs to the "F" tests used in the analysis of variance are available for N independent samples and for certain experimental designs. An excellent discussion of these tests and how to use them is given by Bradley (1960).

Ranking techniques are seldom used in plant work. According to Brown (1954), DeVries devised an estimated productivity method that he called the rank method. The order of precedence in bulk of each species was determined in quadrats of 1 sq. dm. Results of the rank method agreed with those of the air-dry weight-analysis method. DeVries also combined rank by bulk with frequency.

The Method of Ranked Sets

So far, only the ranking of observations has been discussed. An ingenious method by which a ranked sample for observation can be obtained from a subset of samples has been proposed (McIntyre 1952). It apparently has received little attention from range and pasture research workers. Only one reference to use of the method has been found (Ivins 1959, p. 104). In the summary of the discussion on clipping and grazing techniques, it is stated:

Professor Donald outlined a system of sampling which had been developed in Australia by McIntyre. Two adjacent frames are laid down and alternately the area which appears to yield higher and the one which appears to yield lower are selected for clipping. 100 samples cut in this way were found to give the same accuracy as 150 single samples taken completely at random McIntyre (1952). The method had proved of great value on uneven pasture.

The principle of ranked sets can be illustrated by the following example: Suppose one takes three sets of three random samples each from some area to be sampled, and ranks the samples in each set in order of magnitude with respect to total herbage weight. Then, from the first set take the highest ranking sample, from the second set take the middle sample, and from the third set take the lowest ranking sample. The three samples selected for clipping out of the nine will include each rank position from the first to the third.

The frequency distributions of the clipped plots of each of the three ranks will have areas under the curves that are each one-third of the parent distribution. For any particular herbage weight the sum of the ordinates of the three subdistributions will equal the ordinate of the parent distribution. The variance of the mean of three samples, one from each subdistribution, is equal to one-third of the mean variance of these distributions. This is in contrast to the variance of the mean of three random samples, which is one-third the variance of the parent distribution. McIntyre states, "The ranked sample method gives not only an unbiased and more precise estimate of the mean, but all higher moments will also be determined more efficiently by samples selected in this particular manner."

Several frequency distributions were arbitrarily selected by McIntyre to illustrate the efficiency of the method. The means and higher moments of each population and its subpopulations to five ranks inclusive were determined by integration. One of these distributions was a Beta-function, that is, $f(x)=x^{p-1}(1-x)^{q-1}$, $0<x<1$, with (p,q) values of (4, 4). The means and standard deviations of this symmetric, parent population and the subpopulations of samples of the same rank from sets of five random samples are given in the following tabulation:

Subpopulations of ranks:	*Parameter* *Mean*	*Standard deviation*
1	0.695	0.101
2	.587	.096
3	.500	.095
4	.413	.096
5	.305	.101
Total population	.500	.167

The efficiency of estimation of means and variances by means of the ranked sample method relative to

random sampling (100) for the same parent population given above is shown in the following tabulation:

Number of ranks:	Moment: Mean	Moment: Variance (about pop. mean)
2	148	100
3	196	110
4	242	122
5	289	134

The gain in efficiency for higher moments is not high for populations likely to be met in practice. Relative to random sampling as 1, the efficiency of estimation of the mean for moderately asymmetrical populations is not much less than $(n+1)/2$, where n is the number of ranks.

McIntyre discussed various factors that will tend to reduce the efficiency of the method. Extra time is involved in placing plot frames and assessing the material in them. Not all sets of plots will be ranked correctly in order of magnitude. This will not bias the estimate of the mean, but it will lower the precision of the method.

The plots in a set must be fairly close together in order to be ranked correctly by inspection. The plots in the set, then, will not be random samples from the whole area but a clustered sample within a restricted part of it. This will not be a serious problem if local variability is large compared to the whole area.

McIntyre completed his discussion by saying, "The method will be of use where only a sample of the population is to be measured, where random samples can be readily ordered by visual inspection or other rough gauging method, and where the exact measurement of the sample is costly in time or effort."

A field test of the ranked sets method was conducted in early summer, 1962, at the San Joaquin Experimental Range, which is located in the California annual-grass type. Three separate areas were sampled: a bottomland or swale site, a north-slope site without rock and brush, and a rocky, south-slope site with some brush. The vegetation was mature and was very dry on the south-slope site. On the swale and north-slope sites, 36 sets or clusters of two plots each and 36 sets of three plots each were taken; on the south-slope site, 36 sets of three plots each and 36 sets of four plots each were taken. A total of 612 plots in all were used in the study.

Plot frames used in the study were 1 foot square, since previous experience had shown that plots of this size and shape would give, on the average, fairly symmetric distributions of herbage yields. The plot frames in each set were placed about 3 feet apart from center to center. Three observers, working independently, ranked all the plots in each set and kept separate records. After the ranking by each observer was completed for a set, the plots were clipped to a one-half inch stubble height, and herbage was placed in paper bags identified by set numbers and plots within the set. The clippings were ovendried and weighed to the nearest 0.1 gram.

Another test was done in October 1962 on open grassland at the Palustris Experimental Forest, which is in the bluestem-longleaf pine type in central Louisiana. The vegetation was mature and was being grazed at the time of the study.

Three teams, each consisting of two observers, ranked 120 sets of three plots each on separate areas within the same site. This made a total of 1,080 plots for the study. One team used plot frames 1 foot by 2 feet in size; the other two teams used square frames 1.55 feet on a side. After the plots were ranked, they were clipped to ground level; herbage was ovendried and weighed to the nearest 0.1 gram.

The results of both tests were about the same. For sets of three plots each, the average correct ranking for all observers was about 65 percent. It was somewhat lower for the sets of four plots used at the San Joaquin Range and somewhat higher for the sets of two plots. Sets of three plots each appear to be the best on both locations studied. Very little extra time was required in placing the plot frames in a set and in ranking the plots, so the loss in efficiency for this part would be small.

If it is assumed that the efficiency of the method is somewhat less than $(n + 1)/2$, where n is the number of ranks, a rough estimate of the average efficiency from all these tests would be 150 percent. This means that a sample of 100 plots obtained by this method would be equal in precision to a sample of 150 random plots.

From the results of these two tests, the ranked sets method appears to be a promising way of sampling range vegetation for attributes that can be ordered by visual inspection. When the method is adapted for sampling in any particular location, several factors must be considered. Appropriate plot size and shape must be determined for each characteristic to be sampled. The best spatial arrangement of the plots in the set and of the sets in the area must be established. Distances between plots in a set will, of course, be restricted since one must be able to see all the plots at one time in order to rank them correctly. The maximum number of plots in a set that one can rank without excessive loss of time and with fairly high accuracy must also be determined. Also, estimates of observer differences should be obtained, since individuals differ in their ability to rank the plots correctly for the attribute being measured.

DETERMINATION OF FORAGE YIELD AND QUALITY FROM ANIMAL RESPONSES

H. L. Lucas [1]

The purpose of this paper is to make a contribution toward the development of a sound conceptual framework in which the determination of forage yield and quality can be viewed. First, I shall give concepts and in that connection shall try to clarify some terms and shall note the need to think in, and to translate between, two frames of reference, one meaningful with regard to the sward and one with regard to the animal. Next, I shall discuss the interrelations of forage yield and quality with animal performance. Finally, I shall deal with some fairly specific matters involved in using animals to measure forage yield and quality.

THE CONCEPTUAL FRAMEWORK

Dynamics of the Sward-Animal System

A Mode of Expression

Think of some, preferably short, time interval, t_1 to t_2. Call the status of the system at t_1 the *initial* status, and describe this status in both sward and animal terms. Next, think of what goes on during the interval t_1 to t_2, again in both sward and animal terms, relating the happenings to the initial status and bringing out the interplay between sward and animal. Then, consider initial status plus the subsequent happenings to arrive at the status at t_2, the *final* status.

If man does not intervene, the status at t_2 is also the initial status for the interval t_2 to t_3. If man intervenes at t_2, then the initial status for the interval t_2 to t_3 is different from the final status for the interval t_1 to t_2. In either event, the cycle of events described for t_1 to t_2 now recurs for t_2 to t_3. Note that the points in time, t_1, t_2, t_3 . . ., can always be defined in a way that intervention of man coincides with some of them; thus, the complication of man intervening within a time interval can be avoided. Ideas of essentially the same nature have previously been published by the author (Lucas 1960).

Some Simplifying Matters

The sward-animal system is so complex that weather, disease, and the many ways in which man can intervene will be more-or-less disregarded throughout the paper. It will be assumed that no mechanical harvesting of forage is done and that wildlife is not a factor. Also, it will be assumed that the only effect of the animal on the sward is via forage consumption. Clearly, there are other animal effects (e.g., via excretal return and trampling), but, especially on range, these are probably minor.

After the framework is presented, the way in which mechanical harvesting and wildlife can be introduced will be given passing attention.

The Framework

The general picture.—The framework is presented in four pieces (figs. 1 to 4). Figure 1 points up the initial status of the system in plant and animal terms, and also the factors affecting forage produced and forage available per acre during the immediately succeeding time interval. Figures 2 and 3 focus on the happenings in which the animal is involved, thereby bringing out the interplay between sward and animal during the time interval. Figure 2 points up the factors affecting the type and amount of forage consumed per animal, noting the accessibility matter; figure 3 points up the factors affecting forage yield, and those determining animal production and animal yield both per animal and per acre. Finally, figure 4 indicates the principal pathways whereby initial status and subsequent events affect the final status of the system for a given time interval and the initial status for the immediately following time interval.

A critical conceptual point—sward status as the reference axis.—Note the following important matters:

1. Sward status *directly* affects type and amount of forage produced and available.
2. Type and amount of forage produced and available *directly* affect the animal.
3. The animal *directly* affects sward status.
4. The effect of the animal on type and amount of forage produced and available is *indirect*, via the effect on sward status.

Since man can intervene to determine the initial and the subsequent time course of status (by controlling type and number of animals and other factors at will), the initial and subsequent time course of sward status can be viewed as the axis of reference for the system. That is, it can be regarded as the basic factor controlling forage produced and available and thereby controlling animal performance. Many other factors

[1] Acknowledgment of the help in preparation of this manuscript is made to Mary Ann Cipolloni and Dr. R. G. Petersen.

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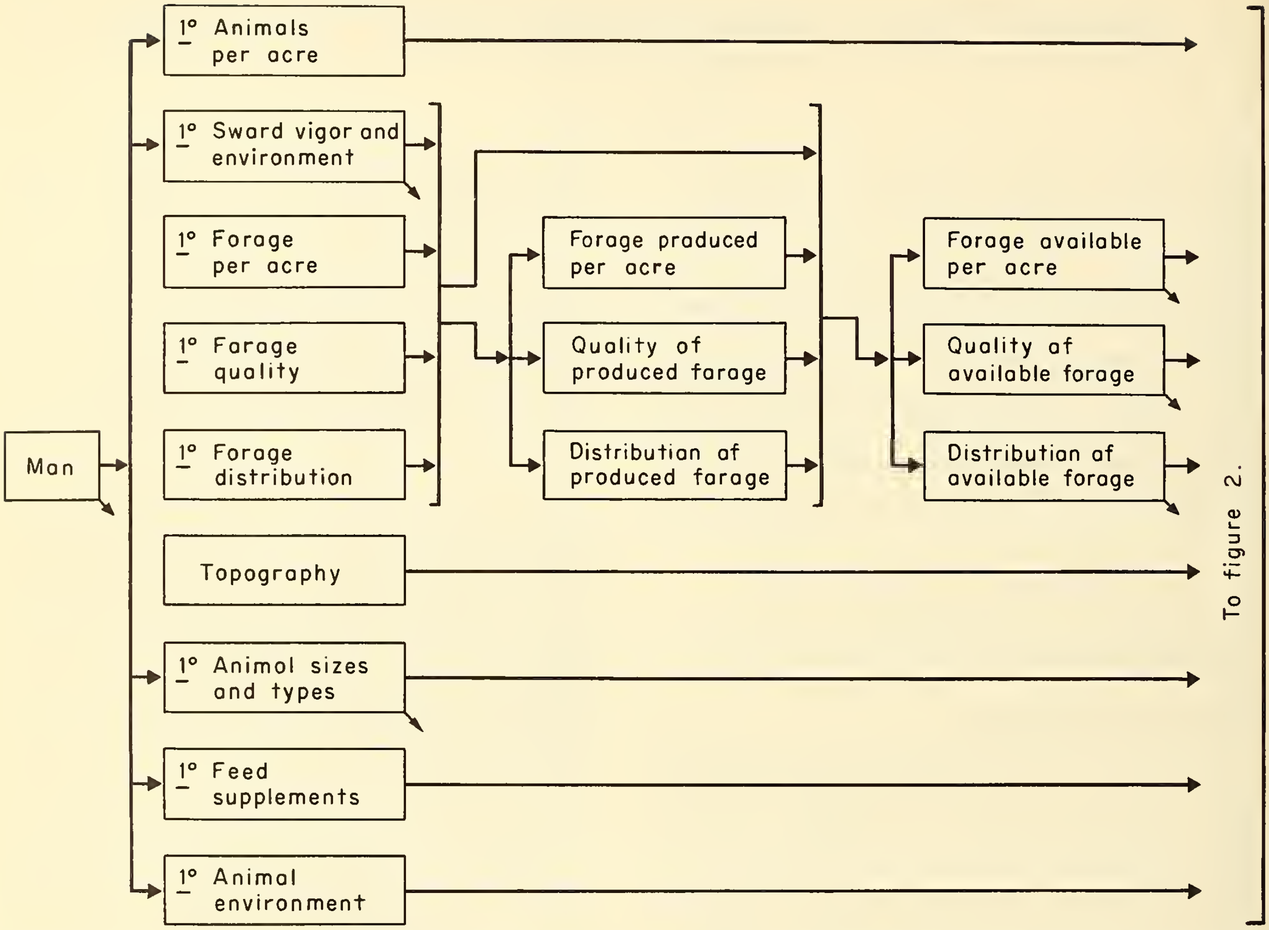


Figure 1.—Initial status of system for the time interval, t_1 to t_2—i.e., the primary (1°) status—and factors determining forage production per acre and forage available per acre during the time interval, t_1 to t_2. The little diagonal arrows indicate factors which have direct effects on initial status for the next time interval t_2 to t_3—i.e., on the secondary (2°) status (see figure 4)—as well as having indirect effects via the pathways of this figure and figures 2 and 3.

affect animal performance (figs. 2 and 3); nevertheless, sward status can be regarded as the basic determining factor and the other factors as conditioners of the animal response.

In the context just developed, many factors commonly considered to be treatment variables (e.g., stocking rate, continuous vs. rotational grazing, constant vs. put-and-take stocking) can be regarded simply as methods of varying the basic treatment factor, the initial and the subsequent time course of sward status. The animal thus simultaneously plays two roles in grazing experiments. On the one hand, it serves as an instrument whereby the experimenter can attain a desired experimental condition (e.g., a fixed time course for sward status) or can attain different levels of an experimental variable (e.g., different time courses for sward status). On the other hand, the animal serves as a device for measuring sward performance.

We are in the position that action and manipulation of the measuring device (the animal) can profoundly affect the item being measured (sward performance). Animal response certainly measures sward performance if other factors affecting animal performance are held constant. But, if only animal response is measured, the results are of limited generalization value, because the initial and subsequent time course of sward status is unknown. Thus, there is no firm base to which to refer the animal responses. In theory this problem can be overcome by proper measurement of initial sward status and its time course.

For the remainder of this paper it will be assumed that proper measurements of sward status can be made and used in interpreting animal response and items computed therefrom. That is, the animal will be regarded as a measurement device. In so doing, however, the important items that affect animal response, other than sward status, must also be taken into account. The de-

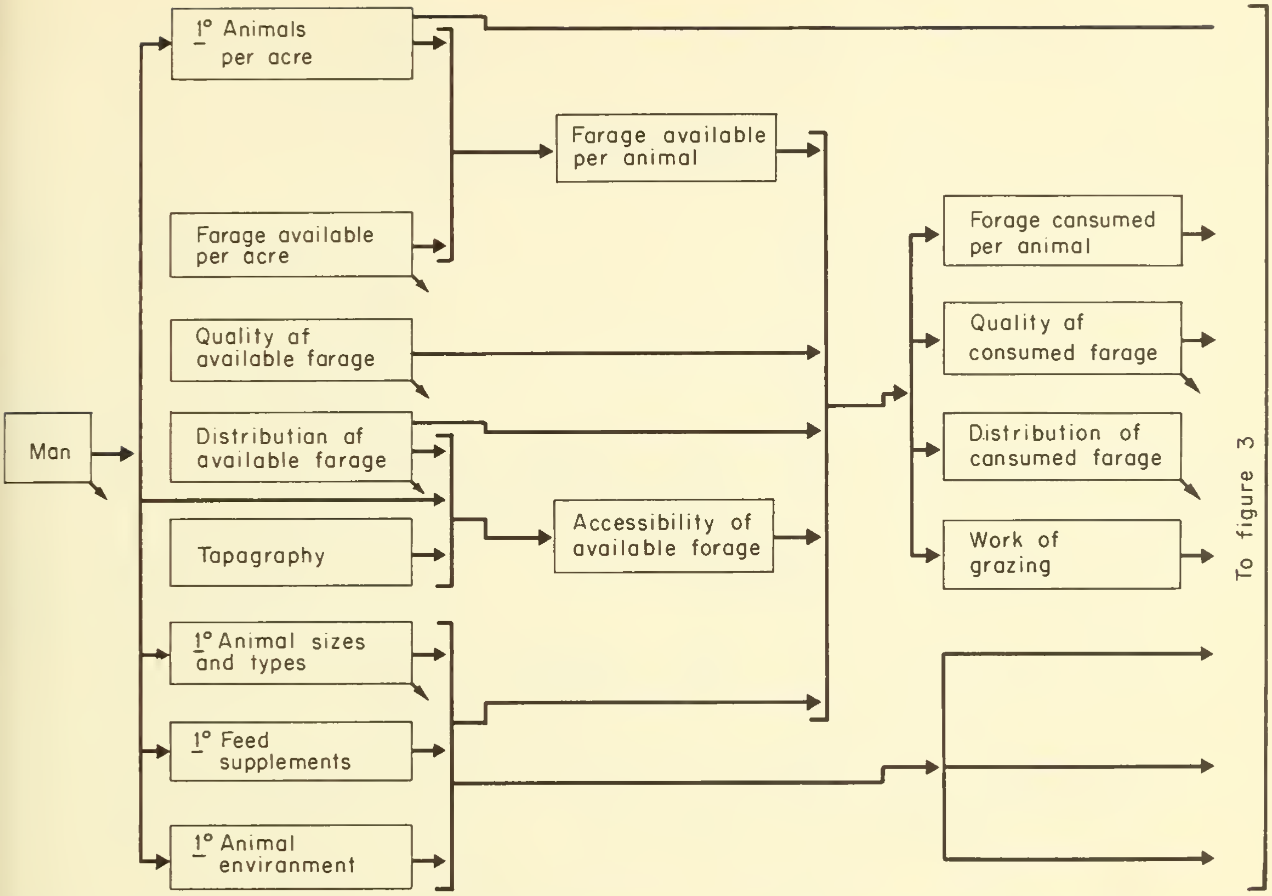


Figure 2.—Factors determining forage accessibility, forage available per animal and forage consumed per animal during the time interval, t_1 to t_2. The little diagonal arrows indicate factors which have direct effects on initial status for the next time interval, t_2 to t_3—i.e., on the secondary (2°) status (see figure 4)—as well as having indirect effects via the pathways of this figure and figure 3.

gree to which these other items can be taken into account greatly influences generalization of the results based on animal responses.

Certain Other Concepts and Definitions

Although most of the terms and concepts involved in and associated with figures 1 to 4 do not need clarification, there are some which, because they either are commonly used ambiguously or are somewhat novel, deserve comment.

Animal type.—"Type" means any relatively homogeneous group of animals; e.g., yearling steers of a certain breed, or mature Hereford cows with suckling calves about 1 month old. It is convenient to consider a cow plus her calf or a ewe plus her lamb(s) as a single animal.

Quality of forage.—The term, forage quality, is usually in the animal reference frame; i.e., it is thought of in terms of nutritive composition or, less desirably, in terms of factors, such as digestibility, which are dependent in part on nutritive composition and in part on animal characteristics. One can, however, think in the plant reference frame; e.g., in terms of ratios of different functional parts of different maturities of different plant species (hereafter simply called "plant parts"). Presumably the latter, if properly measured, are translatable to the animal reference frame, but the converse seems not always to be true.

Forage distribution.—This term refers to the spatial distribution of the forage, not only over the sward area, but also with respect to distance above ground. It is extremely difficult to visualize good ways of characterizing forage distribution in terms that are meaningful from the sward standpoint and from the animal standpoint. From the plant standpoint, interest is in the way plant parts are distributed and, from the animal standpoint, in the way animal nutrients are distributed.

Accessibility.—The concept of accessibility seems to be an important one for range work.

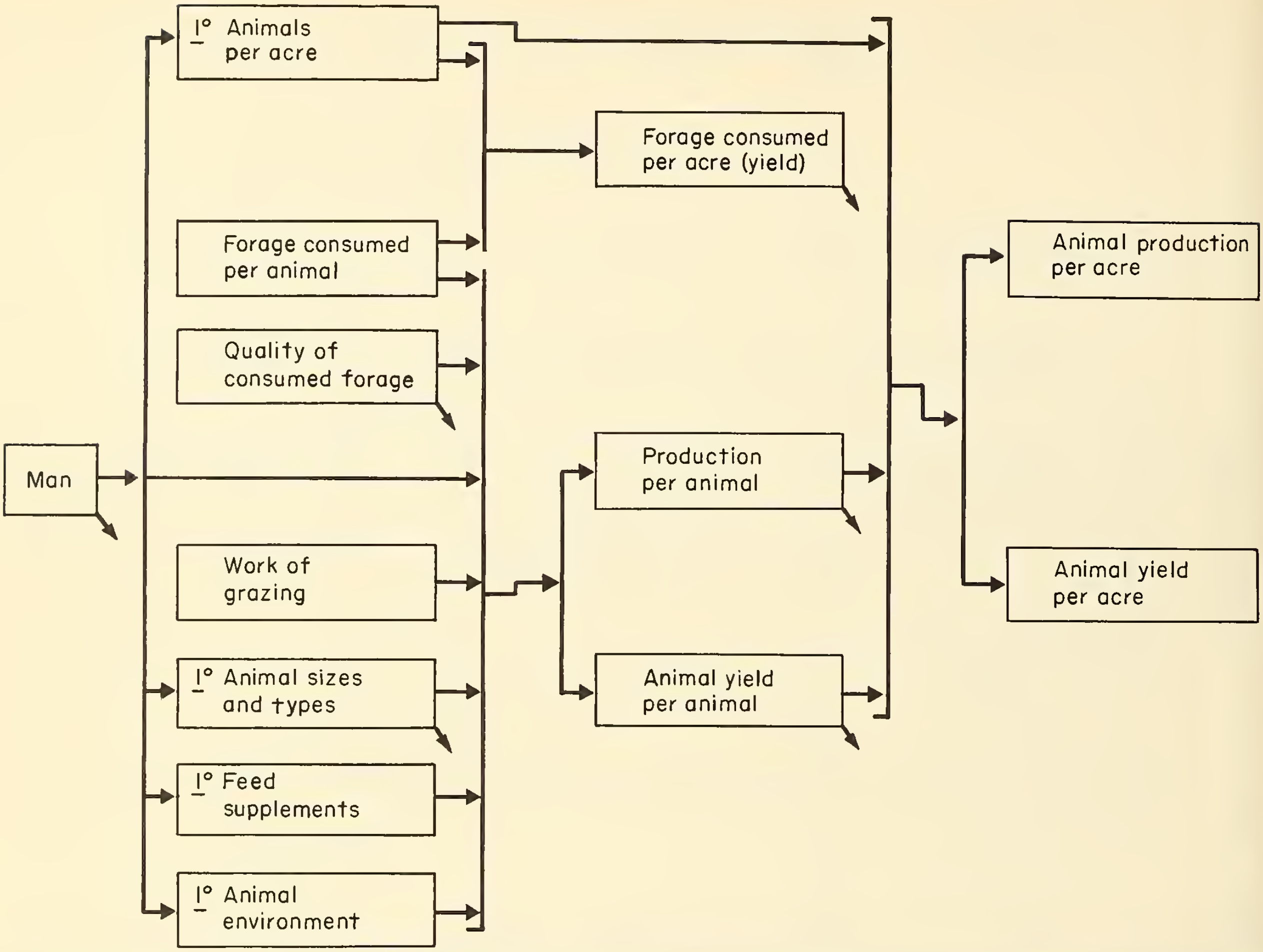


Figure 3.—Factors determining forage yield per acre, animal production per animal and per acre, and yield per animal and per acre during the time interval, t_1 to t_2. The little diagonal arrows indicate factors which have direct effects on initial status for the next time interval, t_2 to t_3—i.e., on the secondary (2°) status (see fig. 4)—as well as having indirect effects via the pathways of this figure.

even though it probably is a minor matter for cultivated pastures. It is difficult to visualize effective terms in which to define or ways by which to measure accessibility. It is clear, however, that, for the most general usefulness, accessibility of available forage should be defined in terms independent of animal factors; i.e., in terms of distribution of plant parts or nutrients, topography, and positions of water sources, salting stations, etc. Topography itself poses measurement problems in terms meaningful from the animal standpoint.

Forage quality vs. pasture quality.—Although it is common to speak in terms of forage quality, there can be other nonanimal items about the pasture which affect the animal measures of forage quality. These other items are encompassed by the concept of accessibility plus certain environmental factors important to the animal. In this paper, pasture quality will be taken to mean the amalgamation of accessibility, the pertinent environmental factors, and the quality of available forage.

Production vs. yield.—It is important to distinguish production from yield. Production is here defined in the same way for both sward and animal, namely, as the amounts of materials which "grow" on the pasture during a given time interval, noting that "growth" may be negative. For yield per acre, however, the definition is somewhat different for the sward than for the animal. For the sward, yield is defined as that part of *forage available* (initial plus produced) that is actually removed (consumed) from the pasture. For the animal, yield is defined as that part of the *animal production* which is harvested from the pasture.

Note that, in a given time period, yield can be less than, equal to, or greater than production for forage and/or animal, but that forage yield

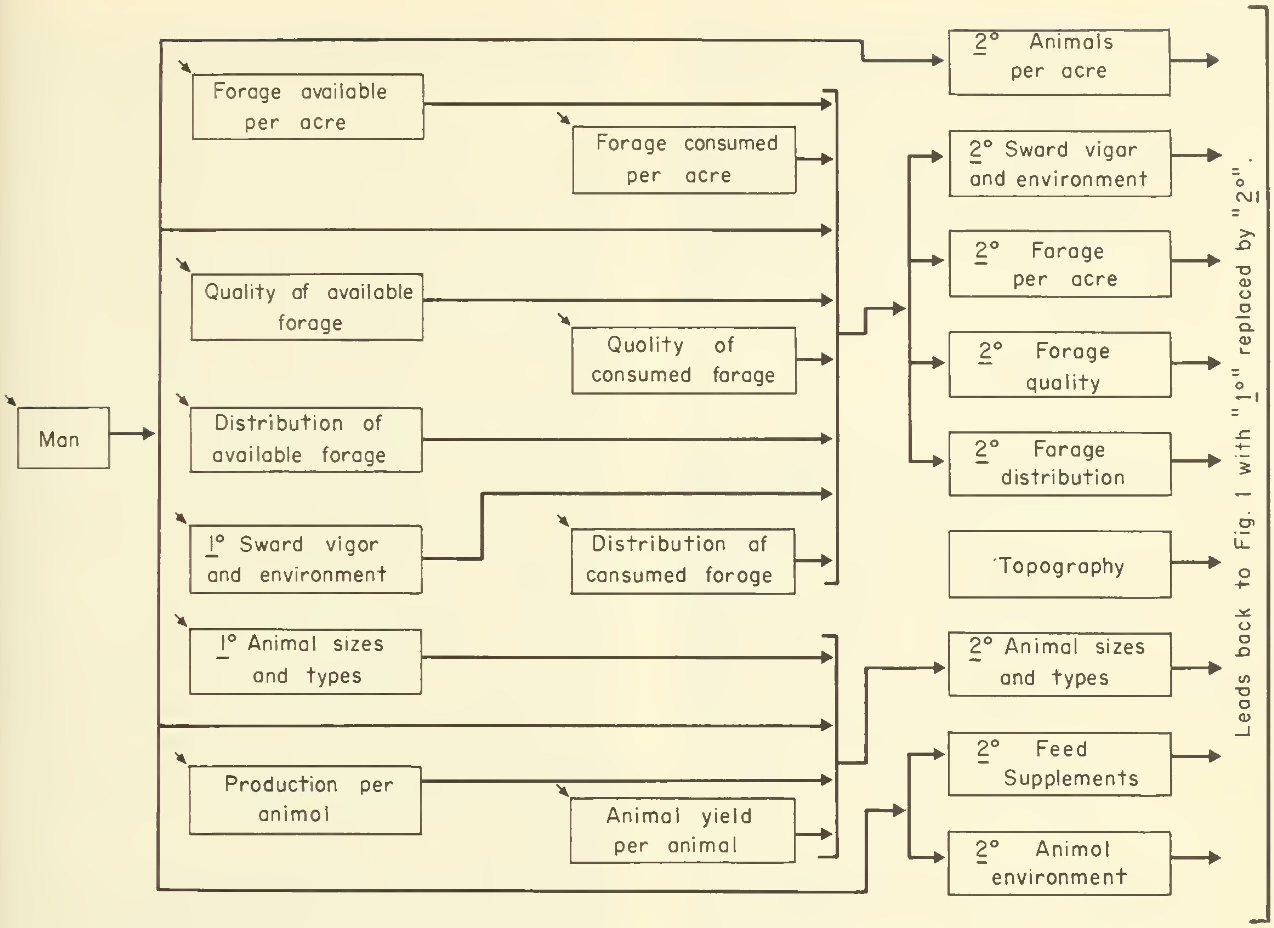


Figure 4.—Factors affecting initial status of the system for the time interval, t_2 to t_3—i.e., the secondary (2°) status.

cannot exceed forage available. Thus, negative yields are possible for animal but not for forage. Actually, the distinction between production and yield of animal materials is often not very important. However, the distinction between forage production and forage yield can be very important, because the forage remaining at the end of a given time period can markedly affect subsequent forage production and, hence, can affect subsequent forage available and subsequent animal performance.

Forage utilization.—The ratio of forage yield to forage available is here defined as the degree of utilization.

Comments about mechanical harvesting and wildlife.—If mechanical harvesting is done, the materials so removed are added to the consumed forage to provide forage yield. Forage consumed by wildlife is also part of the forage yield. If wildlife is not harvested, its animal production is part of the animal production but not of an animal yield. If some wildlife is harvested, however, then that harvest is part of the animal yield.

THE RELATION OF ANIMAL RESPONSE TO FORAGE YIELD AND QUALITY

Analysis of Relations

The focal point of this paper is the determination of forage yield and quality with animals. We must therefore be clear on the interrelations between animal behavior and forage yield and quality and on how these interrelations are conditioned by other important variables in the system.

The Hub of Relationship

The hub around which the relations of animal response to forage yield and quality revolves is the forage consumed per animal and the quality of that forage (figs. 2 and 3). Note the following points:

1. Forage consumed per animal and its quality are in themselves animal responses.

2. Forage consumed per animal multiplied by animals per acre is forage yield.

3. Forage consumed per animal and animal quality reflect the quality of available forage.

4. Forage consumed per animal and its quality are reflected in production per animal.

5. Because production per animal multiplied by animals per acre is animal production per acre, and because production per animal reflects forage consumed per animal and animal quality, the forage consumed per animal and its quality are reflected in animal production per acre. The number of animals per acre is, of course, a treatment factor.

The Key Relationships

There are two critical relationships in which the hub is involved, namely: (1) How forage consumed per animal and animal quality are related to the quality of available forage; (2) how production per animal is related to the forage consumed per animal and its quality. The problems presented are not simple. On the one hand, the amount and the quality of forage consumed per animal are determined not just by the quality of the available forage but also by a number of other factors. Similarly, production per animal is determined by a number of factors in addition to amount and quality of forage consumed.

Factors Determining Forage Consumed Per Animal and Animal Quality

The five principal factors governing forage consumed per animal and animal quality are as follows (see also fig. 2): Quality of available forage; forage available per animal; accessibility of available forage; animal sizes and types; feed supplements. Although many, if not most, qualitative features of the way these factors affect forage consumed per animal and animal quality are understood, there is little understanding of the quantitative features. While a critical study of the literature with the present framework in mind would probably provide a considerable amount of quantitative information, further experimental work is needed. The problems consist both of learning to measure the five factors satisfactorily and of establishing the mathematical forms of the relationships. A brief summary of present knowledge follows.

Effect of quality of available forage.—Crampton et al. (1960a, 1960b) have done promising work based on the idea that the upper limit on feed consumption per animal per feeding is determined by the capacity of the prime reservoir of the digestive tract (e.g., the rumen) and the rate of disappearance of feed from the prime reservoir. For a given size and type of animal, the disappearance rate rests on the physical and chemical makeup of the feed. Work is certainly needed to learn what the important physical and chemical factors are and how to measure them. In lieu of physical and chemical measurements, Crampton et al. (1960b) and Donefer et al. (1960) have used digestion at 12 hours in artificial rumina as the index of disappearance rate and have found it to be highly correlated (r=.90) with the intake of digestible dry matter.

Effect of forage available per animal.—Mott (1960) has outlined the way in which forage available per animal affects production per animal in grazing trials. This effect occurs primarily through the effect of forage consumed per animal. Decreasing the forage available per animal only slightly decreases production per animal until the forage available per animal is less than the amount an animal would consume if the forage were in excess of adequate supply. After that point, production per animal decreases rapidly.

Effect of accessibility of available forage.—Little of quantitative nature can be said about accessibility. Certainly, the less accessible the available forage, the more effort will be needed to graze, and presumably an increase in required effort will, after some point is reached, tend to decrease the forage consumption. Learning a useful way of measuring accessibility would be worthwhile.

Effect of animal sizes and types.—Crampton et al. (1960a, 1960b) consider animal capacity to be proportional to metabolic size (three-fourths power of body weight). Tentatively, this seems to be an adequate way to handle size. As regards type of animal, it is well known that different classes of animals (e.g., cattle, sheep, goats, and deer) desire somewhat different sorts of forage as their diets. There is real need to study the latter problem in more detail.

Effect of feed supplements.—Up to a point, increasing the amount of concentrates offered will ordinarily result in an increase in concentrate consumption and a decrease in forage consumption. After this point, animals will leave some concentrates because they prefer the forage. This is not always true, however, because, if the forage available is deficient in a critical nutrient (e.g., nitrogen, a mineral, a vitamin, or even energy per pound of feed), increasing the amount offered of a concentrate rich in the deficient nutrient can, up to a point, increase the consumption of forage. What is true for concentrates is qualitatively true for roughage supplements, but of course the breakpoints are much different. Proper analysis of data in the literature probably could provide considerable information on the quantitative effects of feed sup-

plements on forage consumption. It is highly probable, however, that additional research will be needed to obtain adequate knowledge about the matter.

Factors Determining Production Per Animal

The five principal factors determining yield per animal are as follows (see also fig. 3): Forage consumed per animal; quality of consumed forage; work of grazing (determined by accessibility of consumed forage); animal sizes and types; feed supplements. Much more is known, qualitatively and quantitatively, about the relations of production per animal to these factors than is known about the relations of forage consumed per animal to the factors governing it. Classically and currently, research in animal nutrition has been and is devoted primarily to the relations between animal performance and the amount and quality of feed consumed per animal. This knowledge encompasses the effects of feed supplements and the effects of animal size and type. There is also quantitative information pertinent to the work of grazing.

Effect of forage consumed per animal.—Much is known about the way consumed feed is partitioned by an animal among various useful purposes and various losses. Working maintenance requirements must be satisfied before an animal can produce. There are many grazing situations in which an increase of 25 percent in the forage consumed per animal would double the production per animal. With a given amount of forage available per acre, only 80 percent as many animals could be carried, but this would still mean an increase of 60 percent in animal production per acre.

Effect of quality of consumed forage.—Much is known about the manner in which quality of consumed feed affects certain aspects of the utilization of feed by animals. Relatively good quantification of the relations between feed composition and digestibility are available, but a limiting factor is the lack of really good methods for chemically fractionating the complex carbohydrates. Some things are known about the way in which quality of forage can affect other aspects of the utilization of consumed feed. For example, some things in forages can cause a shift in the ratio between food energy going to milk and that going to fat storage. Quantitative information on such matters is, however, relatively scarce.

Effect of work of grazing.—Apparently, the work of grazing cultivated pastures is about equal to the work involved in the ordinary activity of animals in dry lot.[2] Animals on such pastures travel about 2 miles per day. Under range conditions distances covered can be many times greater and possibly represent an important energy need. There are data available for estimating the feed equivalent of distance traveled (Brody 1945), but more needs to be known about distance traveled under various conditions. In general, good methods for routine measurement of the activities of grazing animals should be developed.

Effect of animal sizes and types.—Animal size is the primary governor of maintenance requirements. A reasonably good quantification of the relationship is available (Brody 1945; Kleiber 1961). The partitioning of the feed consumed above maintenance needs can, however, be profoundly affected by animal type. Some examples are as follows: The body-weight gain of young animals is relatively low in fat, whereas that of mature animals is high in fat; a milking cow in early lactation may drain body stores to attain high milk production, whereas a cow in late lactation, especially if carrying a calf, puts on body weight at the expense of milk production. There is real need for routine methods of measuring the fat content of body weight changes in the intact animal.

Effect of feed supplements.—The amount and the nature of feed supplements can affect the utilization of the consumed forage. For example, digestibility can be affected either beneficially or adversely, or the ratio between the energy going to body stores and that going to milk can be increased or decreased. The effects of supplements on digestibility of forage are often not of significance, and the previous remarks regarding feed composition and digestibility ordinarily apply. Knowledge about other effects of feed supplements on forage utilization is in the same state as the corresponding knowledge for forage quality.

Summarizing Comments

The most striking feature of the material just reviewed is that knowledge about utilization of feed once it is consumed is much more extensive than the knowledge about factors governing forage intake. Yet, as has been noted, the amount of forage consumed per animal can be a dominant factor controlling production per animal. Crampton et al. (1960a) reported that the relative importances of forage intake and forage digestibility in determining rate of gain were 70 and 30, respectively.

Sufficient reasons exist for continuing to improve knowledge about the utilization of feed once it is consumed. But, in the pasture context

[2] Waldo, D. R., and Moore, L. A. Personal communication.

at least, it appears to be much more pressing to gain understanding about the factors controlling forage consumed per animal and to arrive at quantifications of the relationships involved. The concept of a Nutritive Value Index (Crampton et al., 1960a) should be very helpful in the problem.

USES OF ANIMAL RESPONSE

Orientation

Animal Response and the Goal of Pasture Research

The basic goal is to become able to predict the output of a given sward-animal combination for a given set of input and side conditions. Output is in terms of animal yield per animal and animal yield per acre (including quality of the animal product yielded, a factor which for brevity I have not considered). Input is in terms of the acreage and characteristics of the pasture, and the number and the kind of animals. Side conditions are in terms of expected time course of weather and in terms of things which man might affect through time, such as grazing intensity, addition of soil amendments, and supplementary feeding of animals.

To attain the goal, we must learn how properly to characterize the input and side conditions, and we must also learn quantitatively the relations of output to input and side conditions. To learn these things, various facets of the system should be studied separately, but the mode of study must be such that the knowledge about the facets can be integrated to describe the total system.

The facets emphasized in this paper are those in which the animal is involved, or, in the study of which, animal measurements are valuable. I shall attempt to discuss the use of animal responses in a way integratable into the total picture.

The Central Point of This Paper

The relationships of interest have up to here been viewed in a "forward" way; i.e., in a cause-to-effect sequence. First, we moved from pasture characteristics and other factors to the hub, forage consumption per animal and its quality. Thence, we traced from the hub to animal performance, taking various conditioning factors into account. Now, we shall trace "backwards" from animal performance and various concomitant measures to see what can be learned about the forage.

Measures of Animal Performance

A relatively large number of measures of animal performance might be considered for experimental work, but attention will be restricted to a few important ones. These are as follows:

1. Forage consumed per animal and its quality.
2. Production per animal (for simplicity it is assumed that production per animal and yield per animal are equal).
3. Animal maintenance—computed from body weight, time, and distance traveled. (This might not be thought of as performance; yet the animal "performs" to maintain itself.)
4. Digestibility of consumed forage.
5. Nutritive value index of Crampton et al. (1960a).

Measures of animal performance can be made on animals actually grazing, or they can be made on animals to which cut forage is offered. With grazing, the measures are potentially relatable to the items affecting the consumption of forage on pasture. With cut-forage feeding, the results strictly do not represent what would occur on the pasture from which the forage is cut; the forage which would have been consumed on pasture and the cut-forage consumed are not in general the same in amount or quality. Nevertheless, results with cut forage can aid in understanding and interpreting many of the occurrences on pastures, excluding, of course, items related to accessibility.

Concomitant Measures

There are a variety of subsidiary measures that can be taken concomitantly with measures of animal performance. Included are chemical analyses (nutrient composition) of the available and the consumed forage and measurements with artificial rumina. To aid in understanding both sward and animal behavior, the forage consumed and available can also be described in terms of plant parts. Most of these procedures will not be discussed, but an important use of artificial rumina will be noted briefly. In general, these measures are necessary to "explain" animal performance and to establish sward-animal relationships.

Measurement of Forage Quality on Pastures

Measurement by Forage Consumed Per Animal and Animal Quality

Forage consumed per animal and animal quality reflect the quality of the forage available. Thus, if factors other than quality of available

forage are standardized in a grazing trial, forage consumed per animal becomes an index of the quality of the forage available. If one or more of the other factors (forage available per animal. accessibility of available forage, size and type of animal, or feed supplement) are treatment variables, then forage consumed per animal is not a good index of quality. This does not mean, of course, that forage consumption is not a valuable measure of response.

In principle, forage consumption and its quality can be measured in a number of different ways, although in practice each way is beset with difficulties and inadequacies and needs improvement. Some important methods are as follows:

1. *Measurements of the sward itself.*—e.g., by the cage and mower-strip clipping methods plus appropriate chemical and botanical analyses.
2. *Digestive indicator methods.*—These provide estimates of the amount and the digestibility of forage consumed per animal.
3. *Computation of the nutritive value index.*—This involves forage consumed per animal and digestibility of the forage.
4. *Computation of "effective" feed units consumed per animal.*—This involves assignment of feed equivalents to the maintenance and the production of the animals.

Measurement by Production Per Animal

Production per animal reflects amount and quality of forage consumed per animal and animal quality and, thus, indirectly reflects quality of available forage. Hence, as with forage consumption, production per animal is an index of quality of available forage if appropriate factors are standardized.

Measurement of Forage Quality by Feeding Cut Forage

Experimentation with cut forage, if done properly, can be an extremely valuable tool for working out the quantitative relationships that exist in many facets of the sward-animal system. All the tools of nutrition research can be utilized in the effort. The experimentation should be accompanied by serious attempts to develop appropriate quantitative theory.

The key matter is to study a wide variety of mixtures of various plant-parts of various species and maturities. For relationships to be seen easily, the affecting factors must be varied widely. In too much research, there are too few treatments and unduly narrow ranges of the treatment variables.

Such widely varying mixtures fed in controlled amounts, with appropriate measurements made on forage and animal, would improve our knowledge about the relation of animal response to forage of specified quality fed in known amounts. Such mixtures furnished to the animals in oversupply, perhaps with the components offered separately (cafeteria style) would yield valuable information about the relations of amount and quality of forage consumed to the amount and quality of forage offered.

In addition to other valuable information, the data so obtained would permit improvement of the formulae to compute "effective" feed units. Also digestion trials run with such mixtures would serve to calibrate the digestive indicator methods for local conditions.

The Nutritive Value Index

Crampton et al. (1960a) have found their Nutritive Value Index to be highly correlated with rate of gain of sheep ($r=0.90$). The index is computed as follows:

$$V=CD/W^{.75}$$

where

C=weight of forage dry matter consumed per day.
W=weight of animal.
D=digestibility of the dry matter.

The quantity $C/W^{.75}$ is called the Relative Intake.

Donefer et al. (1960) found the digestion of forage cellulose at 12 hours in artificial rumina to be highly correlated with the Relative Intake ($r=0.83$) and even more highly with the Nutritive Value Index ($r=0.91$).

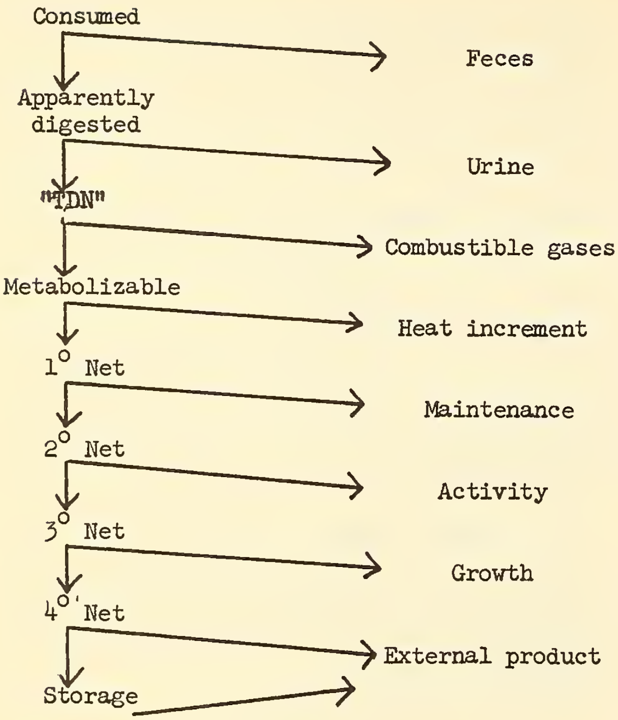
These developments are particularly exciting and seem to offer a good start toward the understanding and the quantification of the relations of amount and quality of forage consumed to the quality of forage available.

"Effective" Feed Units

The Partition of Consumed Feed

Before discussing the computation, the meaning and the use of "effective" feed units, it is worthwhile to review the fate of feed once it is consumed.

The way in which feed flows into various categories of loss or use is brought out by the following diagram:



Maintenance plus activity are often added together and called working maintenance. With work or pleasure animals, such as horses, a large part of the activity is, however, productive, so that only the "useless" activity is included in the working maintenance. With growing and fattening animals, there is no external product; thus, growth plus storage is the production. In the case of milk animals, milk plus offspring constitute production. For range cows or ewes, the calves or lambs (plus wool), respectively, are the production.

The diagram is ordinarily used to describe total energy flow, and we shall use it in that context. In essence, however, it holds for any individual nutrient, including water.

Computation of "Effective" Feed Units

Effective feed units can be expressed in terms of TDN, Net Energy, or on some other basis. The computations are made on the assumptions that the working maintenance requirement of animals is proportional to some power of body weight (usually three-fourths or seven-eighths power), and that production requirements are proportional to production. The factors for maintenance can be modified to encompass varying amounts of activity associated with grazing, and those for production, to take into account the type and the composition of the product.

The Quantity Measured by "Effective" Feed Units

By comparing the mode of computation with the partition diagram, it is seen that "effective" feed units represent the quantity designated as 1° Net. The fractions of feed energy lost via feces, urine, combustible gases, and heat increment are not included (hereafter these fractions will be called the "lost proportion" of the feed). Thus, it is soundest conceptually to compute "effective" feed units in terms of Net Energy. For practical purposes this matter is not important, assuming, of course, that the maintenance and production coefficients used are proper for the feed-unit system employed. In other words, whatever the feed units may be called, they all measure 1° Net.

The "effective" feed units can be computed for each animal on a pasture. The sum of "effective" feed units consumed by all animals on the pasture (or the number of animals per acre times the "effective" feed units per animal) is the yield in terms of "effective" feed units per acre.

If a supplement is being fed, one simply subtracts the feed units supplied by the supplement from the "effective" feed units computed from maintenance and production to arrive at the "effective" feed units supplied by the pasture, both per animal and per acre.

Modified "Effective" Feed Units

If appropriate data are available on the composition of forage consumed and on the way in which composition interacts with type of animal, the "lost proportion" of the consumed forage can be estimated or, equivalently, the "effective" feed units can be adjusted so that they correspond to the "effective" amount and quality of forage consumed. How well such corrections can be made is a question, but it seems that examination of the data in the literature should provide usable procedures.

Advantages of Using "Effective" Feed Units

Assuming that correct conversion coefficients are employed, and restricting consideration to a given pasture, the following important "theorem" holds:

> For all combinations of type of animal and management practice (including stocking rate) that result in the same amount of forage consumed per acre and the same quality and distribution of consumed forage, and providing that the "lost proportion" of the forage is the same quality and distribution of consumed forage, and units per acre will be the same.

Thus, for example, if one can manage things such that the amount of forage consumed per acre

and its quality and distribution are set, the "effective" feed units per acre will be nearly the same for all ruminants.

There is a "corollary," as follows:

For all combinations of type of animal and management practice that result in the same amount of forage consumed per acre and the same quality and distribution of consumed forage, and providing that one can correct for the "lost proportion" of the forage for all the types of animals, the "effective" amount and quality of forage consumed per acre will be the same.

The advantage of the "effective" feed unit approach is thus seen to be as follows: Insofar as the conditions of the "theorem" and the "corollary" can be met, the "effective" feed unit yield per acre and the "effective" amount and quality of forage consumed per acre, respectively, are independent of the type of animal involved. Under the required conditions, then, experimental results obtained with one kind of animal can be used to estimate carrying capacity and production per acre for another kind of animal. To do so does require, however, some additional knowledge. The first thing that must be known is the amount of effective feed units or "effective" forage that would be consumed per animal for the kind of animal of interest under the pasture conditions involved. The second thing is the production per animal that will ensue from the consumed feed. This is the basis of using "tester" animals in grazing trials.

Basis of Conversion Factors

As the base for working maintenance, it seems reasonable to take Morrison's (1956) figure of 8.0 pounds of TDN per day for a 1,000-pound animal, and also to vary this requirement in proportion to the seven-eighths power of body weight as he does. Figures given by Brody (1945) indicate that the expense of travel is about 0.02 TDN per 100 pounds per mile. From the results [3] it appears that one should add, for work of grazing, an amount equal to 0.02 (X–2) pound TDN per 100 pounds, where X is the number of miles traveled per day.

For production measured by body gain (or loss), the coversion factors vary widely, depending on the fat content of the gain or loss. In young, thin animals a pound of gain represents only about one pound of TDN, whereas in old, fat animals, the figure is 4 pounds or more of TDN. Appropriate figures can be worked out from slaughter data, but an index of fatness of the animal is necessary to use them properly. For milk production a good figure is 0.31 pounds of TDN for each pound of 4-percent milk produced.

[3] Waldo, D. R., and Lane. Personal communication. 1961.

Use of "Testers"

Use of "tester" animals and the computation of the results of grazing trials has been outlined by Mott and Lucas (1952). "Testers" are animals of a specified kind that remain on an experimental pasture for the duration of the grazing period of interest. Two or more kinds of "testers" may be placed together on the same pasture. In contrast to the "testers," the other animals, although they should be of the same general class as the testers, can otherwise be nondescript and can be on the pasture varying lengths of time. Yield of "effective" feed units per acre is computed, using all animals. Consumption of "effective" feed units per animal is computed for each kind of tester, as also is production per animal. From these data, then, carrying capacity and production per acre can be computed for each kind of tester.

There are two key matters determining the reliability of the approach. The first is that correct conversion factors are used for each sort of animal involved. The second is that all animals have essentially the same grazing habits; i.e., that the conditions of the "theorem" or "corollary" are met.

Experimental Errors

Measurements of quantities, such as product per animal and product per acre, contain errors which result from: (1) inherent variation among swards upon which the same conditions have been imposed, and (2) inherent variation among animals subjected to the same environment.

Product Per Animal

For measures such as product per animal, which are used to determine forage quality, the sward component of error is the result of variations in the general level of quality and in the time trends in quality among swards treated alike. The animal component of error in the quality measures is attributable to variation in the general level of production and in the time trend in production rate among animals treated alike.

Petersen and Lucas (1960) indicate that the experimental error (coefficient of variation) per pasture for average daily product per animal, C_G, may be estimated from the equation

$$C_G=\sqrt{\frac{(157.2)^2}{t}+\frac{(17.3)^2}{a}+\frac{(225.4)^2}{d}}$$

in which

t=length of grazing period in days.
a=number of different animals appearing on the pasture.
d=total number of animal days supported by the pasture.

"Effective" Feed Units Per Acre

For measures such as "effective" feed units per acre, which are used to determine forage yield, the sward component of error also results from variations in the general level and in the time trend among swards treated alike. The animal component, however, is the result of variation among animals in the difference between the actual and the computed "effective" feed unit consumption and in the time trend of this difference.

The experimental error (coefficient of variation) for "effective" feed unit consumption per acre, C_E, may be estimated (Petersen and Lucas 1960) from

$$C_E=\sqrt{\frac{(101.1)^2}{t\sqrt{s}}+\frac{(118.4)^2}{d}}$$

where

t=length of grazing period in days.
s=pasture size in acres.
d=total number of animal days supported by the pasture.

Other Measures

Equations have not been obtained for other measures of quality and quantity. However, the errors for product per acre are approximately the same as those for product per head. The errors for animal days per acre are approximately the same as those for "effective" feed units per acre.

SUMMARY

A conceptual framework within which to view the sward-animal system in a dynamic way is presented. The time course of sward status is regarded to be the reference axis of the system and the basic factor controlling amount of forage produced and available, and also forage quality. These factors in turn can be regarded as controlling animal performance, acting through the hub, forage consumed per animal and its quality. It is stressed, however, that many factors can influence the relation of the time course of sward status to the forage consumed per animal, and of the forage consumed per animal to animal performance. Important factors are forage available per animal, accessibility of available forage, kind of animal, feed supplements, and animal environment.

The determination of forage yield and quality from animal responses is then considered in the conceptual framework developed. It is pointed out that animal performance always reflects forage yield and quality, but that animal performance is a trustworthy index of forage yield and quality only if the other factors conditioning the relationship are standardized or can be properly taken into account.

Uses of certain measures of animal performance are discussed. Consideration is given to some alternate ways of measuring forage consumption and digestibility (e.g., cage and mower-strip methods, digestive indicator methods and the Nutritive Value Index). Computation of the "effective" feed units consumed (e.g., TDN) from animal maintenance and production is also discussed, and some of the advantages of this approach are explained. Formulas for computing expected experimental errors for production per head, "effective" feed units per acre and related measures are given.

SAMPLING PROBLEMS IN THE MEASUREMENT OF RANGE VEGETATION

T. C. Evans and W. G. O'Regan

W. G. O'Regan and I must confess to some difficulty in sorting out a specific approach to our topic. We had been forewarned by our committee that the early speakers in this session would in part preempt discussion of the statistical aspects of their respective presentations. Having heard them we agree that this was proper, but several weeks ago we were in a quandary as to what could possibly be left for us. After some discussion, we surmised that you among others are not satisfied with existing sampling procedures to determine the amount of livestock and wildlife forage, that statisticians and range and wildlife habitat specialists alike do not have the answers to their pressing survey problems, and that perhaps you would entertain a suggestion or two on how the search for improved methods might be pursued. This is the tenor of our offering.

Upon scanning the literature, our impression is that livestock and wildlife forage surveys and experiments seek generally to measure some response in vegetational yield, growth and regrowth, or condition and trend, using a variety of meaningful criteria, among them frequency, composition, area, volume, and weight. From these we have chosen, for specific examination, composition as a measure of condition, for which we write the parametric model

$$C_j = \frac{\sum_{i=1}^{n} w_{ji}}{\sum_{i=1}^{n} w_{\cdot i}}$$

where

C_j=the required ratio
w_{ji}=dry weight of species j, $j=1 \ldots J$ on plot i, $i=1 \ldots n$
$w_{\cdot i}$=dry weight of all species on plot i

If this were the assignment and we had all the time, money, and manpower necessary, we would do precisely what the model suggests: Clip, sort by species, dry and weigh every blade of vegetation on all possible plots, and compute the ratio of the weight of each species to the total weight of all species. Beyond doubt we would know the composition at the time of the inventory; beyond doubt the procedure would be philosophically sound, scientifically valid, and patently ridiculous. Among other things, we would by virtue of clipping have altered the stand beyond all hope of using the composition data intelligently.

We know also that in the real world we do not have all the time, nor all the money, nor all the manpower, and therefore will have to settle for less, and usually considerably less, than a complete census. How much less is the problem, or at least part of it, for if we accept less than the census we are promptly confronted with other decisions. We know that accepting less than a census implies that we will settle for an estimate, and we well know that estimates differ. They differ in precision and in cost even for the same field technique and sampling method. If we admit a variety of techniques and sampling methods, the differences in estimates due to procedure offer a bewildering number of alternatives. Among them we ask, is there a better method, or perhaps even a best method? The answer to this question is the principal objective of our sampling studies.

No matter which response and criterion we choose, whether yield of dry forage, growth in volume or basal area, condition measured variously, or trend in composition, the problem is the same. We try to first imagine a cost-free, error-free model, then promptly confess we must be satisfied with less, and set about to find a simple solution which may satisfy our need, or at best an optimum solution which offers the greatest reward for the money invested.

Lacking the resources to satisfy the parametric model, we would next fashion an estimator, possibly

$$C_j = \frac{\sum_{i=1}^{I} w_{ji}}{\sum_{i=1}^{I} w_{\cdot i}}$$

where

C_j=estimated ratio
w_{ji}=as above, except $i=1 \ldots I$
$w_{\cdot i}$=as above, except $i=1 \ldots I$.

At this point, we can become realistic. Most of us would immediately condemn this model because of what we already know and have heard about clipping. Indeed, the literature contains testimony that for such a model to be successful, the clipping and drying cost would be exorbitant.

The literature also contains evidence of the advantage of the method of double sampling, provided a low-cost variable (x) can be used to estimate the high-cost variable (w). Double sampling suggests that clipping and drying might be confined to a small sample of plots, as I above, and further that on each clipped plot observation be made of the number of contacts, by species, made by a series (say 100) of pins suspended from a fixed frame exactly bounding the plot. Tally of the pin count by species (x_{ji}) would be less costly in both time and effort than clipping and drying, and if the tally is strongly correlated with dry weight, we believe that the double sampling procedure would be profitable. The required large sample of pin counts would be made on a number (M) of plots such that M is greater than I, and the revised model becomes

$$\hat{R}_j = \frac{\sum_{i=1}^{M} x_{ji}}{M} \left[\frac{\sum_{i=1}^{I} w_{ji} \Big/ \sum_{i=1}^{I} w_{\cdot i}}{\sum_{i=1}^{I} x_{ji} \Big/ I} \right]$$

where the new symbols are

x_{ji}=number of hits on species j on plot $i=1 \ldots M>I$,
M=number of plots in large sample of pin count only,
I=number of plots clipped and pin counted, $i=1 \ldots I$.

In double sampling there is no restriction that plots in the large and small samples must be equal in size; nor is there a restriction that the number of pins must be equal. Therefore, the final model may contain terms in both plot area and number of pins per frame to admit analysis of their effect on the properties of the model.

The above model was developed independently at the Southeastern Forest Experiment Station by Ripley as a method for estimating weight of deer browse in mixed hardwood stands, and at the Pacific Southwest Forest and Range Experiment

Station as a method for estimating composition of range grass in the annual grass type. Because more data are available, and because the analysis is further along there, we confine discussion to the California experience. The specific case here is composition, but it should be remembered that the model is a general one which with ingenious adaptation might be extended to similar problems in yield, growth, or condition and trend.

The properties of the model are the focal point of discussion. We are concerned with what these properties are, how they contribute to inference, if and how they can be controlled, and finally how to judge among several alternative estimators.

Broadly, any estimator should be examined for three general properties: Bias, precision, and efficiency. In one or another way, all are affected by the size and configuration of the sampling unit. Very small plots in vegetative surveys often exhibit bias, perhaps because observers are uncertain of the exact boundaries of the plot or because of a tendency either to exclude or include plants growing on the plot margin.

Large plots, with a lower ratio of perimeter to area, tend to be free of the bias. Large plots display lower variance per unit area, and observations on them tend to be normally distributed even if the distribution on small plots is distinctly nonnormal. Similarly, for nonnormal parent distributions, means from large plots approach normality faster than those from small plots. And generally, large plots cost less per unit area, assuming the cost of plot location is independent of plot size.

Among these simple generalities, the instructive and salient point is that the properties of the estimator are controllable by manipulating size and configuration of the sampling unit and the number of observations. The implication is clear: if bias, shape of the distribution, precision, and cost of obtaining the observation are influenced by size of the plot and by the number of observations, a comprehensive test over a wide range of each variable should disclose the relationship and possibly reveal the critical region of plot size above which bias becomes tolerable. It should show the effect of plot size and sample size upon the shape of the distribution, leading to either confirming the validity of existing normal theory or disclosing a need for a new probability model. Finally, it should permit an estimate of the effect of plot size on cost, and hence on efficiency.

Comprehensive studies of this kind require considerable meticulous planning, tedious hours of drawing samples, and a prodigious amount of computing. For example, in sampling studies field plots are often nested in such manner that plots may be combined and recombined to form larger plots or decomposed to form smaller plots. As an illustration, we may imagine a homogeneous range condition sampled by 20 random large plots, each 6 feet square, and each subdivided into 36 1-foot squares. If the pin count and the dry weight were recorded for each 1-foot square, it would be possible to examine the relationship of bias to plot size by comparing the mean of all 720 small plots to the mean of any sample drawn according to the model.

Similarly, we may estimate variance in a variety of plot configurations from 1 to 36 square feet in size; for each size we may test the assumption of normality, or other postulated distributions, by drawing repeated random samples from the 720-plot population. We may test the effect of changing the size of the counting plot while holding the size of the clipped plot constant, or reverse this procedure, or alter both plots; we may alter the number of pins per frame and test its effect on precision; and finally, with observations of cost per sampling unit, we may estimate efficiency of all the combinations.

Those of you who have made similar sampling studies will quickly appreciate the enormity of the task. You will also appreciate what a welcome tool the electronic computer is in this kind of study; indeed, without it these studies might never be attempted. With it, we are limited only by our imagination and skill.

The remainder of the discussion will fall into two major parts: the general approach and results to date of sampling studies conducted at the Pacific Southwest Forest and Range Experiment Station. Under general approach we will discuss theory, discontinuous cases, continuous cases, and the problem of populations that cannot be mapped. Results will be presented from two large programs to study discontinuous populations and a smaller program applied to a sample of a nonmapped population. We have no results for continuous populations.

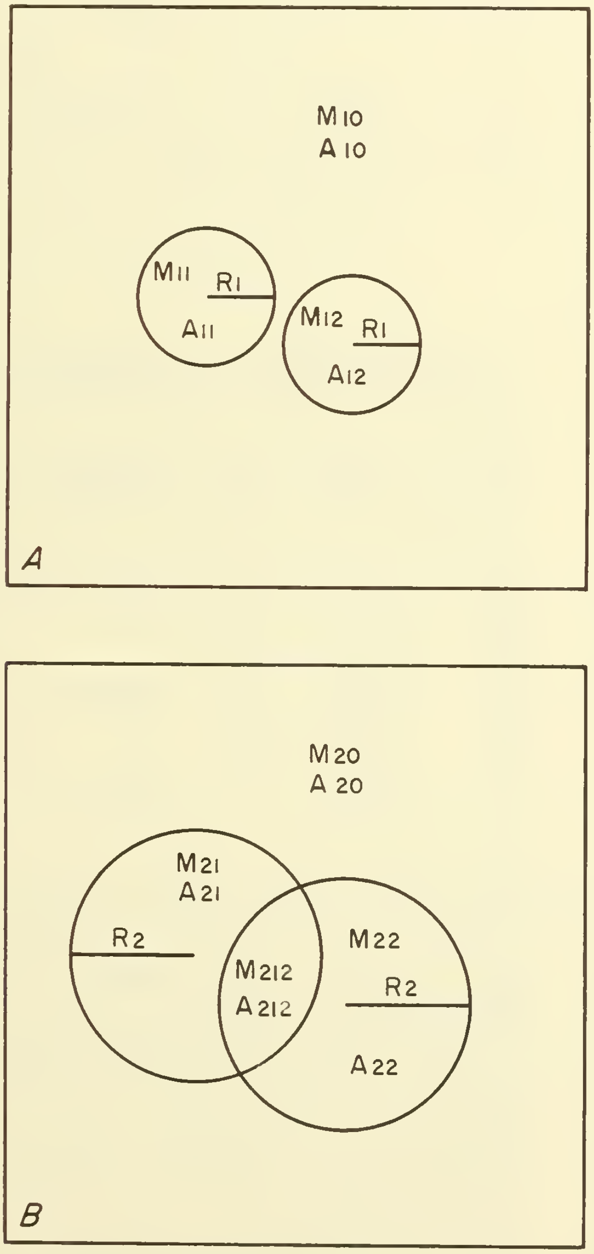
Our general theoretical approach is that for a set of physical objects fixed in two or three dimensional space, a given sampling rule (e.g., take a point at random and construct a circular plot of radius R) determines a probability distribution of the measurements associated with these objects and this rule. For example, given a two tree forest of area A (fig. 1), a rule that says take a point at random, construct a circular plot of radius R_1, and construct measurement M_1 (volume per acre, for instance) based on the trees in that circle, gives the population of measurements illustrated in figure 1, *A*.

If the radius of the circular plot is increased to R_2, a new population of measurements is created (fig. 1, *B*). Obviously, a point falling outside the circles surrounding a stem gives a plot

with zero measurement. If a point falls into the area common to both circles (fig. 1, *B*), both trees are included on that plot. All plots of radius *R* containing a given stem will have their centers within the circle of radius *R* having the stem as center.

If the trees are of different cross-sectional area with the first stem being smaller, and if point sampling is used with basal area factor (BAF) 1 and BAF 2, populations as illustrated in figure 2 are created.

The extension of these ideas to forests or stands of brush with many stems is conceptually easy but a somewhat difficult graphical and computational problem. The two necessary ingredients of the statistical population are the measurements derived from clusters of trees and the probabilities of obtaining these measurements in a random drawing. The probabilities are provided by the areas associated with each cluster. From these ingredients, sampling distribution can be inferred. Combined with cost data, information about sampling distributions can lead to more economical sampling procedures.



Measurement	Probability
M_{10}	$\frac{(A-2\pi R_1^2)}{A}$
M_{11}	$\frac{\pi R_1^2}{A}$
M_{12}	$\frac{\pi R_1^2}{A}$

Measurement	Probability
M_{20}	$\frac{(A-2\pi R_2^2)}{A}$
M_{21}	$\frac{A_{21}}{A}$
M_{22}	$\frac{A_{22}}{A}$
M_{212}	$\frac{A_{212}}{A}$

Figure 1.—Effect of plot radius upon the population of measurements obtained from a forest of two trees on area A.

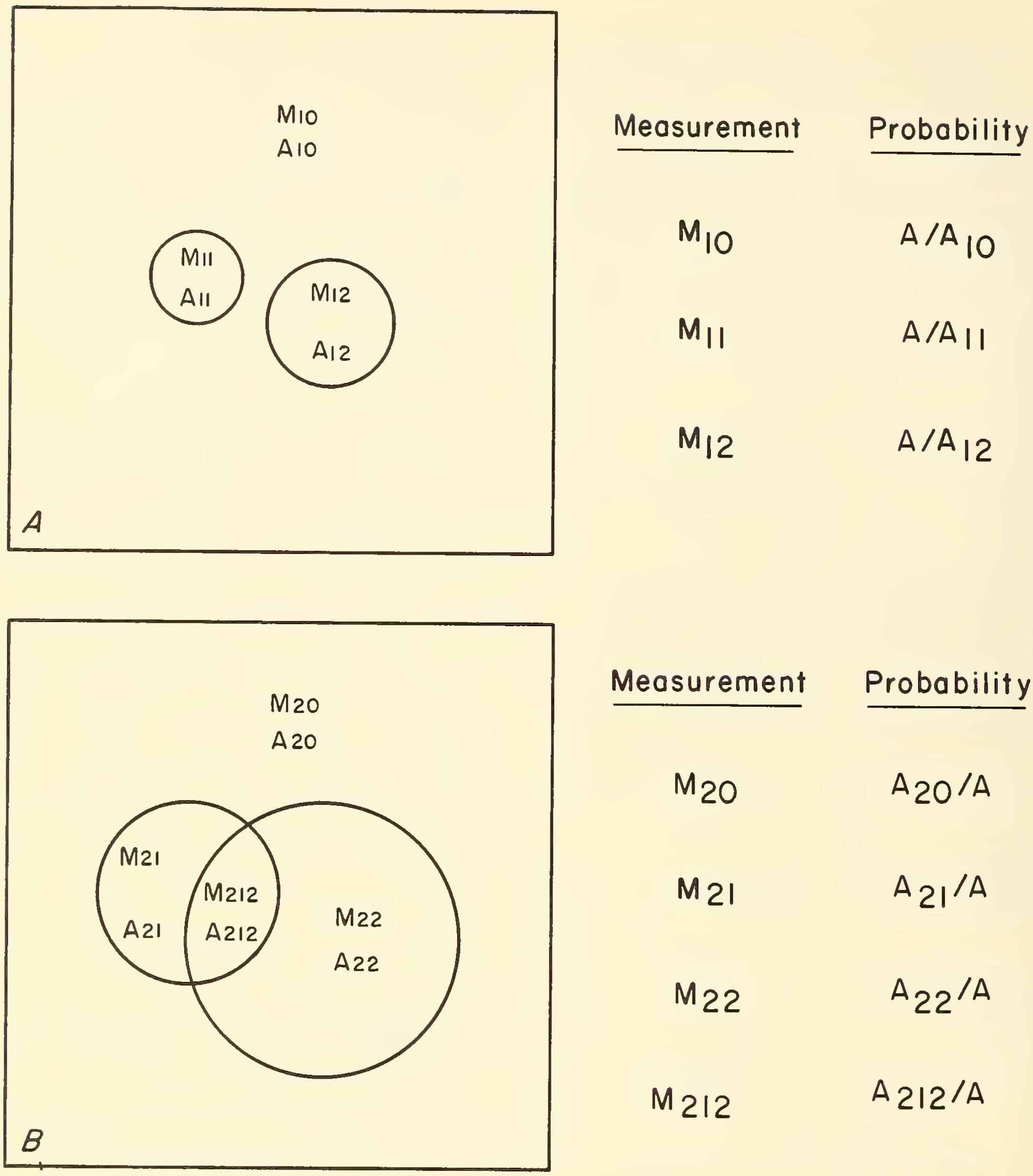


Figure 2.—Effect of basal area factor upon the population of measurements obtained from a forest of two trees on area A.

Areas and associated measurements can be computed, but with reasonable effort for trivial "forests" only. However, close approximations to areas can be obtained by counting dots within relative areas for relatively fine meshes of points installed on the forest area. An IBM 701 computer program for point and line sampling and a 704 program for circular plot sampling have been developed to do this.

Results of applying the 701 program to forests of various kinds have been published (Palley and O'Regan 1961). A paper on the 704 results is being prepared. This manuscript compares point and circular plot sampling.

As an example of the 704 program technique, the effect of plot size on a measurement of total density of seeded bitterbrush was determined. This stand of bitterbrush, 28 by 328 feet, contained 588 plants. Circular plots ranging from 0.002 to 0.024 acre give the results shown in table 1 and figure 3.

The accuracy of approximation of relative dot counts to relative area will, of course, vary directly with the fineness of the mesh. So, too,

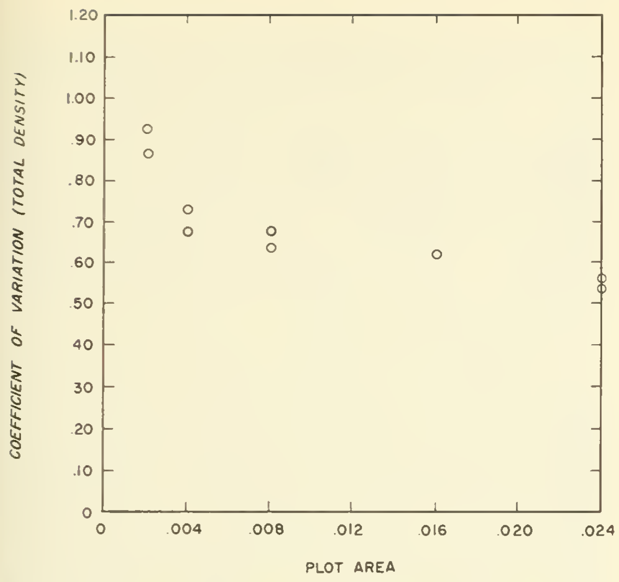


Figure 3.—Coefficient of variation of total density as a function of plot area.

TABLE 1.—*Machine approximations in study of plot size and variance in sampling for density*

Plot area (acre)	X coordinates first point	Number of points in grid	Variance of total density	Coefficient of variation of total density
0.002	0.0	3,485	294,171	0.9224
	.8	3,485	261,383	.8695
.004	.0	3,485	216,385	.7911
	.8	3,485	195,513	.7520
.008	.0	2,296	164,610	.6900
	1.0	2,296	147,275	.6527
.016	.0	3,485	131,487	.6167
.024	.0	3,485	113,229	.5723
	.8	3,485	106,841	.5559

will the machine time involved. Table 1 gives some idea of the relationship of number of dots in the mesh and accuracy of the approximation. Small plot radii evidently give rise to areas that are harder to approximate.

So far, we have discussed problems giving rise to discontinuous populations. Some sampling rules give rise to continuous measurements. For instance, the rule "take a point at random and measure to the nth plant" gives rise to measurement varying continuously from zero to some maximum value. The distribution of measurements will, obviously, depend upon the distribution of plants and "*n*." It would be desirabe to make some generalizations about this relationship. To date, no unifying idea corresponding to clusters of trees and associated areas has suggested itself. It might be necessary to generate large empirical distributions for various "*n*" and for different collections of plants to establish general relationships—if they exist. The production of these large empirical distributions should not be too difficult on a modern computer; the provision of mapped sets of plants might be a greater stumbling block.

There will exist populations of great interest for which any segment small enough to be fully mapped and described would probably be too homogeneous to provide a measure of variability. A way out of this difficulty suggests itself. One could take a relatively large sample spread over enough area and of enough complexity of configuration that it in itself becomes of considerable interest because it measures the variability in the population and contains the raw material of a number of different sampling plans.

A simple example is the problem of satellite points—how many and how distributed—to characterize forests for unit area control (UAC). To draw a map of an area of any size in the detail necessary to determine for any point that point's classification is a formidable task. However, a large sample of locations and associated satellite points could be taken. The satellite points could be rearranged by number and relative position to study the effect of these factors upon the variance, say, of the sampling distribution of estimated proportions.

A little work has been done along these lines. Figure 4 shows the effect of number of satellite points—for a fixed pattern—upon the variance of the estimated proportion of forest area for two relatively large samples in UAC II (a classification of land for management purposes). The uniformity of the results suggests that, for these forests and for the pattern of points selected, three points are about optimum for estimation purposes.

Current work at the San Joaquin Experimental Range has led us to consider the effect of size and number of clipped plots, number of pins, and number of frame counts upon the variance of the estimate of weight composition provided by a certain ratio estimate, described earlier. We propose to construct a very large number of samples wherein numbers of plots, pins, and frames vary, to study the effect upon the variance of the estimate. We will use the large number of plots measured at the San Joaquin Range as raw material.

A 704 program has been diagramed and discussed, but coding has not begun. Fortunately all the data are on cards, but unfortunately only one size of clipped plot was used. If concentric circles or nested rectangles had been clipped, the important variable clipped-plot size could

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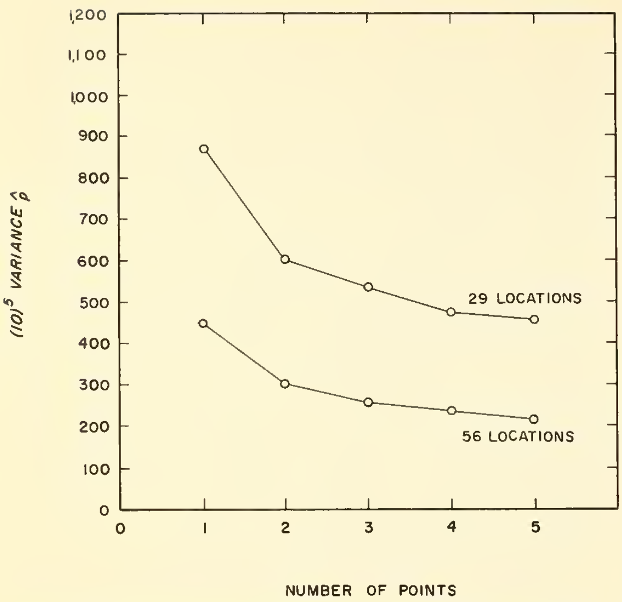

Figure 4.—Variance of estimated proportion of land in UAC II as a function of number of points at a location, for two forests.

have been studied. We should with some work be able to provide information leading to a more nearly optimum relationship between number of clipped plots, number of frame counts, and number of pins per frame.

The experience in California is one in imaginative methodology, coupled with ingenious planning and productive exploitation of the capacity of electronic computers. The proposed work in the annual grass range can be quickly extended to the rest of that type. The larger challenge is to promote and expand similar work in the vast area of the other types and species, including not only grasses but shrubs and low tree forms as well.

We conclude with the observation that there is in this meeting a distinct unhappiness with the status of range surveys, and that this is a tacit indictment of the methods produced by 30-odd years of research. There is also a certain awareness that the problem is a universal one, not unique to range and wildlife habitat research. Campbell (1959) pointed out that the interest in and need for methodology of understory survey and experiment are shared by at least five substantive fields of research.

Fire research needs estimates of the volume of combustible fuel in the understory. Watershed research needs information on the effect of understory on water use and storage. Forest management research needs data on the understory as competition and as an influence on forest soil and soil moisture. And, of course, some of the problems of range and wildlife habitat research are under discussion here. Each field has contributed its bit, but the accumulated bits fall woefully short of fulfilling the need.

In view of this urgency and universality, one way to organize the research attack would be to isolate the whole problem of understory survey methods in an analytical unit under the direction of a senior scientist, amply supported by computer hardware and a staff of statisticians and analysts. It would be premature to guess at the time required to produce usable solutions or the cost of such a program. We can be sure only that the effort will be neither easy nor cheap, but we get a glimmer of the possible results from the modest beginning in California. At this writing, the significant question is: can we afford anything less?

COMMITTEE REPORT ON VEGETATION MEASUREMENT AND SAMPLING

SUMMARY OF PAPERS

Reliable techniques and methodologies are fundamental requisites to an evaluation of vegetation responses and treatment effects. Although much research has been conducted, the inadequacy of our knowledge as to what plant attributes to measure, and how to measure and sample them, is perhaps the greatest deterrent to progress in range management and wildlife habitat research.

Papers in this section present a review of current knowledge and discuss several new concepts in measuring and analyzing plant attributes and responses.

Herbage yield is closely related to animal production and is one of the best quantitative measures of plant response in grazing treatments and ecological investigations. Direct measurement of herbage weight by harvest is accurate, provided that plot location and boundaries are unbiased, and that the kind and parts of plants to be clipped are clearly defined. Double sampling (clipping and weighing herbage from a few and estimating from a large number of plots) lessens the time needed to sample yields. Herbage weight may be indirectly and rapidly measured by association with other plant attributes, such as height, numbers of plants, and foliage cover. The relation of weight to other attributes should be continually checked to avoid large error from improper use of correction terms. Herbage

weights should be taken over as short a period of time as possible to avoid changes by leaching and translocation of nutrients.

Livestock are often used to measure forage yields and quality. Various means of using animals for this purpose are estimation of forage consumed per animal, computation of effective feed units, determination of digestibility, and the nutritive value index. Formulas are available for computing the experimental errors to be expected per pasture, for production per head and effective feed units per acre in terms of length of trial, number of individual animals per pasture, number of animal days supported, and pasture area.

A conceptual framework was viewed in a dynamic way that brings out the interplay of the components of the sward-animal system as affected by man. The status of the sward and its time trend can act as the reference axis for the system. This reference axis reflects what's done to the pasture, and at the same time it controls the production of forage and, via food consumed, the performance of the grazing animal.

The relation of animal response to forage yield and quality was discussed in terms of the cause and effect factors involved. Hub of the relationship is forage consumed per animal. A considerable amount of quantitative knowledge about the reaction of the animal to the forage consumed exists, but there is pressing need to learn much more about the factors affecting the type and amount of forage consumed per animal.

Density, i.e., the number of individual plants in a specified area, has been used to show the effects of man's impact on populations, the association of plant components in competition, and the relationship of plants to environmental factors other than man.

Density measurements have been hampered by time requirements for counting individuals, definition and recognition of individuals, and patterns of distribution. Newer distance (or nonplot) methods are helping to simplify density measurements, although they are not suitable to all types or situations. The Morisita angle-order approach and Catana's wandering quarter offer possibilities for sampling nonrandom populations, especially shrubs and forbs. In many situations the counting of individuals on plots is still the most efficient method for density determination.

Density values have application in plant population surveys where mechanical difficulties are not prohibitive; in autecological studies of single species populations, especially shrub types or stands of tree reproduction where the objective is density; in timbered sites where the objective is relationship of tree density to understory vegetation; in describing population composition for use in long time records; and in studies where plant distribution patterns are related to environmental factors. Some new fields of work employing density of single or mixed species populations are (1) solar energy conversion in plant populations, (2) growth and production of plant populations, and (3) the pattern, aggregation, segregation, and symmetry of population in relation to man's use of rangelands.

Cover is the proportion of the ground covered or occupied by vegetation, rocks, litter, or other material. Only a few of the many methods for measuring plant cover have been adequately tested or compared to determine their relative accuracy or efficiency for the various plant communities. First, plant cover has not been well defined, and it has many connotations. Second, plant populations are extremely variable. Some are simple, others complex, and they occur in random, regular, or contagious distributions. Therefore, a single technique is unlikely to suffice for sampling cover.

In the past, comparative tests of cover sampling methods have been made on populations of unknown quantities and complexities. The tested methods were applied with personal modifications and often with prejudice. Also, in many instances sampling procedures are neither independent nor randomly applied.

Rating or scoring and ranking methods offer distinct possibilities for providing efficient estimates of various plant attributes, although much work is needed on where and how these methods could be used. Parametric statistical methods are already available for analyzing data obtained from some rating or ranking procedures. Nonparametric methods are rapidly being developed. Rank order statistics show great promise for obtaining improved sampling efficiencies as evidenced by the method of ranked sets. Great strides can probably be made in this direction since so little work has been done in this field.

DISCUSSION

General discussion following presentation of the papers brought forth the following points:

Measurement of herbage yields. The meaningfulness of weight determinations is questionable in view of the rapid changes in vegetation and the differences in weight-time peaks of different species. Too often weight is accepted as a direct measure of productivity, whereas actually it is merely an index to production at any specific time. This criticism of weight applies equally to other measures of vegetation; however, most other measures are more readily thought of as indices. Where rapid variations in time are important, rapid weight inventory methods are required. These include estimates, double sampling,

production indices, and perfection of such devices as capacitance meters. Staggering of sampling over the replication during the period of measurement also will tend to minimize the time variation factor.

Plant area measurements. No single pin angle is "best" in point sampling. The angle depends upon the particular attribute measured and upon leaf angle of the species measured. Vertical pins might be best for basal cover, whereas pins inclined to some specific angle might be best for foliage area of a certain species.

Plant density and distribution. Distance measures can be used to determine types of plant distribution, but two kinds of distances are necessary for such determinations. Distance measures present no particular problems in data processing. Density is of questionable usefulness for expressing change due to treatment over a period of time. Weather strongly influences numbers, especially for annual plants. This weakness may or may not be overcome by expressing density in relative terms. The value of plant "shoots" rather than "individuals" as a sensitive measure of change was stressed; "shoots" are not only more sensitive to change but are also more easily defined than "individuals." The particular method most useful for determining plant density and distribution depends entirely upon the population to be sampled.

Distance measures probably are most useful in range research for autecological studies and for sampling shrubs. Angle-order and wandering-quarter methods should be considered if stands are nonrandom: however, angle-order is a very tedious and inefficient method for determining density. Quadrats probably are still most useful for determining density of most herbaceous species.

Plot ranking technique. Distribution of ranked plots should be such that within-set plots are regularly distributed as far apart as possible but still close enough to permit accurate ranking, and that the sets themselves are randomly distributed at intervals depending upon vegetation strata. Usually, the greater the number of plots within a set the greater will be the efficiency, as long as the plots still can be accurately ranked. The balance between plot size, numbers, distribution, and efficiency of ranking has not yet been determined. Plot ranking may not be practical for sampling all species individually. It is useful for total production, but individual species composition must be obtained by separate techniques. Accuracy of ranking probably will not be affected by amount of vegetation on the plots. The usefulness of ranking is not subject to theoretical limitations; it can be applied to all plant attributes, such as density, cover, flower stalk numbers, and weight. Ranked plots will never be inferior to a random sample distribution of the same number of clipped plots as are clipped in the ranked sets. Ranked plots rapidly gain efficiency where vegetation is widely variable over a small area. This method is still so new that little is known about it. However, the method appears very promising and is scheduled for further testing over a variety of vegetation types.

Animal response as a measure of forage. Generally, published T.D.N. (total digestible nutrients) requirement factors for beef cattle are considered adequate for range cattle if the maintenance requirement is increased slightly. Although digestible energy is related to feeding value of forage, gross energy is not related. Artificial rumen determinations probably more nearly reflect live animal digestion if used in conjunction with pepsin digestion. A good routine method to assess fat content of animal gains is needed. The reversal of Dr. Lucas' equation for determining the nutritive value index was suggested as a possible method for computing economic gains of the animals. Although past effort has been concentrated upon processes to simulate grazing, perhaps more important yet is the need to relate what the animals select to what the particular pasture has to offer.

Measurement sampling problems. To date, the basic computational approach to sampling has involved only objects fixed in two-dimensional space; objects fixed in both space and time have not been studied. The raw data, primarily vegetation maps, needed for such studies are scarce and difficult to obtain; possible sources for such maps are aerial photographs and existing chart quadrats. The trained individuals capable of doing basic sampling work are in short supply, but an adequate staff could be obtained if sufficient money were available. Any increase in a basic computational program should be accompanied by increased financing at the field level to permit the collection of field data necessary to the program.

General comments. Population measures of individual plant characteristics are sensitive indicators of plant population vigor, and hence range trend. Such characteristics include height of basal leaves or seed stalks, leaves per shoot or fascicle, length and width of blade, and size and number of seed heads. These measures are sensitive to change and are affected before grosser characters of population such as basal area, density, and composition. Methods studies should be conducted by both special techniques projects and by the regular research projects. Part of the value of techniques specialists is consultation with regular project workers to assist solving methods problems peculiar to particular areas. The qual-

ity standard of many past methods studies can be severely criticized. Great care should be taken to conduct well thought-out studies that include both adequacy and efficiency of the method at both field and data processing stages. Preparation of guides is suggested to assure that future techniques studies will be of proper design to yield meaningful results.

RECOMMENDATIONS

Although the total experiences in range research have produced a vast number of techniques and a variety of methods for sampling range vegetation, a great void exists in the present state of knowledge of their bias, precision, and efficiency. To fill the void the committee recommends a deliberate and comprehensive approach. This would necessitate the organization of an analytical unit under the direction of a senior scientist, amply supported by computer hardware and a staff of statistical and mathematical analysts. However, centralizing computing services for range research is thought inadvisable.

This committee suggests that the biometric group not only conduct methodology research of their own but also that they assist other researchers in the formulation, testing, and analysis of methodology problems under specific conditions and vegetation types.

Some of the more important needs as brought out in the papers and discussion are as follows:

1. Test the correlation of yield with other plant attributes or factors that can be more easily and cheaply measured.
2. Analyze current studies of weight determinations as a possible means of furnishing additional information on variance and measurement techniques.
3. Test cover sampling techniques on synthetic populations with varied size and shape of individuals, single and multistoried populations with discrete and indefinite individuals and other variations and complexities that are likely to be encountered in native plant populations. Such tests would provide information on both accuracy and precision of the various methods. After the methods are tested on synthetic populations, they should be tested and compared on native plant populations to determine their suitability and precision in field application.
4. Expand investigations in the use of scoring or ranking methods for measuring various plant attributes, particularly weight and cover.
5. Further explore the possibility of evaluating quality and consumption of range forage through digestive indicator methods, nutritive value indexes, and "effective" feed units consumed per animal.
6. Test the accuracy and efficiency of methods, especially distance measurements, to sample range vegetation.
7. Develop relationships of single and multiple plant population density in relation to growth and production of vegetation.
8. Explore the use of density as a means of describing the pattern, aggregation, segregation, and symmetry of plant populations.
9. Further suggestions: Provisions should be made for specific problems in range research to be analyzed and freely discussed through informal clinical sessions. Researchers from several Forest Service Experiment Stations, State Experiment Stations, and universities should be included. Also, future conferences should include an expository session on useful concepts of modern mathematics, e.g., symbolic logic, sets, vectors, functions, mappings, transformations, and matrices.

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Range Site Measurement and Evaluation

EXPERIENCE IN SITE-EVALUATION METHODS FOR TIMBER PRODUCTION

Warren T. Doolittle

Since the subject is site, it is first necessary to define the term. According to the Society of American Foresters' (1958) standard forest terminology, *site* is "an area, considered as to its ecological factors with reference to capacity to produce forests or other vegetation; the combination of biotic, climatic, and soil conditions of an area."

This definition may seem somewhat narrow and limited for application to some of the more ecological matters on range which are to follow; yet it does adequately serve the purpose of this paper, which deals with site evaluation in reference to timber production.

In the past, in referring to site—especially site in relation to productivity—most foresters have tended to consider soils and topography as the only factors that determine site. Today another concept is coming into use more and more among foresters, and with it another term: *Total site.* This is still undergoing the pangs of definition. Hodgkins (1959) and Hills and Pierpont (1960) interpret total site as including all the factors of environment and vegetation, and they attempt to evaluate or quantify the relationships of these factors to the productivity of the site. The proponents of the total-site concept plead particularly for greater use of both major and minor vegetation as indicators of site.

The subject of site, if covered thoroughly, would fill a large book. Obviously, in the space allotted, it is not possible to approach complete coverage. Therefore, this paper will be limited not only to site studies in timber production, but also mostly to attempts to relate productivity to soil and topographic factors (soil-site), with some discussion of the total-site concept.

SITE INDEX

The Need for Site Classification

Why do we need to be able to classify forest land according to productive capacities? The following passage from Hodgkins (1959) answers this question, in part, and also gives a rough approximation of the current status of site work in the Southeastern United States:

> The history of forestry in Europe shows us that as forest management becomes more intensive, site classification also becomes more intensive. At first there is only the crudest of productivity grading of forest sites, based on obvious characteristics of the forest and of the physical environment. There follows a stage of quantitative productivity grading, of ever increasing refinement. . . . Eventually, economic pressure for maximum efficiency in forest management focuses attention on attributes of forest sites other than productivity for one or two tree species and there begins an advanced stage of total site classification. . . . In the Southeast, we can scarcely be thought of as being beyond the stage of quantitative grading of forest site productivity.

Determining the productive capacity of land should be one of the first steps in setting up an intensive forest-management plan. Good estimates of productivity—when combined with such factors as age, silvicultural treatments, product objectives, and economic considerations—can be a powerful tool in management. Such information is especially important in regions where there are several species to manage—species often capable of growing on the same land—and where there are definite differences in the productive capacity of the land.

Expressing Productivity (Site Index)

The ultimate expression of productivity of land is in terms of monetary values. Yet this level of values is so many times removed from the land that it is first necessary to express productivity in terms of growth. Growth in terms of volume or weight (depending upon the product) would be an ideal expression. However, besides the productive capacity of the land, there are often so many other factors that affect growth —such as age, density of stocking, and stand composition—that an expression of height growth alone has come to be recognized as a measure of site. This measure of site, usually the height of dominant and codominant trees as related to age, is called site index; it is usually related to a base age of 50 or 100 years.

Site index then becomes the system or basis for stratifying the productive capacity of the land. To be a useful measure of productivity, site index in turn must be related to growth and yield in terms of cubic feet, cords, board feet, pounds, tons, or some other useful measure of wood products. This is usually done through studies of age and stand density in terms of volume or weight by site-index classes.

Although the expression of site index is based on measurements of trees, it is not always possible to find suitable trees for this purpose. The trees available may be of the wrong species or may be too young or too old, or the land may be bare. Hence, there is a need for being able to estimate or predict site index from the land itself—or possibly from low-vegetation indicator plants, if they are present.

INDICATOR PLANTS

In Europe and Canada, and to some extent in the Northern United States, indicator plants have been found to be a useful means of recognizing and stratifying land according to site productivity (Westveld 1954). Cajander (1926) recognized five forest types or sites in Finland: Dry heath, moist heath, low-lying heath, spruce and broadleaf tree-peat moors, and pine-peat moors. He found a strong correlation of growth with age and site. Cajander used a system of a few key plant species to identify site; he usually used lesser vegetation in this indicator work, but he also used some tree species.

However, Cajander's system of indicator plants has not always functioned. For example, in southern Europe, Cajander's practice of working with a few species having narrow ecologic amplitudes (either present or absent) has not been possible. Here it was necessary to work with plants that had characteristically wide ecologic amplitudes. In other words, it was necessary to use all or a great number of species in a plant community and to relate site productivity to relative abundance of these plant species, usually the lower vegetation.

The situation relative to indicator plants in North America appears to be similar to that in Europe. Plant communities seem to be simpler and to possess narrower ecologic amplitudes in Canada and northern latitudes than farther south in the United States. Gagnon and MacArthur (1959) found that ground vegetation was correlated with site quality of white spruce in Quebec—even on lands formerly cropped for agriculture. Hills and Pierpont (1960) have been using lower vegetation as indicators for several years in Ontario. And Daubenmire (1962) recently found seven habitat types for ponderosa pine lands in eastern Washington and northern Idaho; these types or sites were based on an analysis of low vegetation and were related to the height growth of pine.

In southwestern Alabama, Hodgkins (1960), recognizing the problems of complex plant communities and individual plant species with wide ecologic amplitudes, was still able to relate site index of longleaf pine to indicator plants. His indicator plants included both overstory and ground-cover plants in a total plant-community concept.

Aside from the existence of complex plant communities in the United States, much of our forest land, especially in the East, has been drastically disturbed by fires, grazing, clearing, and cropping. These conditions probably limit many of the known methods of using indicator plants in delineating site productivity of the land. But, in the light of several recent studies in which these techniques have been demonstrated, more emphasis should be placed on new studies in this field, especially where it seems possible to relate this system to studies of environmental factors on a total-site basis.

SOIL-SITE

Physical Properties

The term *physical properties*, as used here, is broad; besides including physical properties of soil, it covers topographic, geographic, and climatic factors.

One of the earliest workers in soil-site relations was Haig (1929), who found that the site index of young red pine plantations in Connecticut increased as the amount of silt and clay in the A horizon increased.

Another early worker in soil-site relations was Turner (1938), who studied second-growth shortleaf and loblolly pines in Arkansas. He concluded that site index of these species was most closely associated with steepness of slope, depth to the B_1 horizon, and soil texture.

Auten (1945) reported on a soil-site study of yellow-poplar in Tennessee and in Kentucky and several other Midwestern States. He found that the site index of yellow-poplar was related to depth of the A_1 horizon, depth to a tight subsoil, aspect, exposure, and slope position.

Coile (1948), who has been working on soil-site problems in the South since the middle 1930's, has probably accomplished more in this field than any other person. Coile's main philosophy on the productive capacity of soils is that available moisture is the key to better sites, and that aeration and rooting space also go hand in hand with availability of water.

Specific physical soil properties that Coile found important as related to the site index of

southern pines on the Piedmont soils of North Carolina were the depth of the A horizon and the imbibitional water value of the B horizon. Later studies by his students in the Coastal Plains of the South indicated the importance of these same properties, although in terms of different values.

In the oak forests of the eastern uplands, several soil properties and topographic factors have shown up as important in prediction equations for site index: Depth of the A horizon, texture of the A horizon, texture of the B horizon, total soil depth, position on slope, aspect, and steepness of slope. Workers on oak sites include Gaiser (1951), Trimble and Weitzman (1956), Doolittle (1957), and Carmean (1961).

Zahner (1958), in a study in southern Arkansas and northern Louisiana, found that on mature soils the site index of loblolly and shortleaf pine was related to thickness of the surface soil, content of clay in the subsoil, and steepness of slope. Other recent studies of importance include that of Myers and Van Deusen (1960) on ponderosa pine in the Black Hills, where they found that site index was related to parent material, total depth of soil, position on slope, steepness of slope, and aspect; methods of predicting sweetgum site index by Broadfoot and Krinard (1959), who found that texture, internal drainage, and external drainage were important physical properties in Mississippi River Valley soils; and Della-Bianca and Olson (1961), who studied soil-site relations of five hardwood species over a wide area of the southeastern Piedmont. The results of the last study gave only weak prediction equations, and it was concluded that too many soil conditions were covered in the study. It is also possible that techniques used for measuring soil and other site factors were not precise enough. However, the weakness of the results of this study should be kept in mind, because it illustrates a point that will be taken up again later.

Chemical Properties

Though Coile (1948) recognized that chemical properties (nutrient elements) affect site index, he seemed to feel that nutrient deficiencies were usually not so limiting as physical properties and that, when nutrient deficiencies did exist, they would usually be reflected in various physical properties.

This interpretation of the relative importance of physical and chemical properties is probably correct most of the time, but it should be pointed out that several studies indicate the extreme importance of certain nutrient elements as important factors to the site index of trees on certain soils. For example, Voigt et al. (1957) showed that northern Minnesota soils with high levels of calcium, magnesium, potassium, and nitrogen were four times as productive as soils with low levels of these nutrients.

To summarize on the point of physical versus chemical properties: the important point to remember is that in soils the same factors that govern availability of water in the soil are often the same as those that govern the supply of available nutrients (Voigt 1958).

Since our main concern is soil-site productivity, a lengthy discussion of nutrition and fertilizer research in forestry would be out of place here. However, the importance of such studies should not be minimized. There is a great need to ferret out those soils that are limited in production because of nutrient deficiencies. This problem will become more acute as more and more intensive cultural treatments are practiced, and especially as irrigation and genetically superior trees (hybrids) are more widely used. With this intensification of cultural treatments will come an increased need for, and use of, fertilizers in forestry.

Soil Survey Interpretations

Turner (1937) studied the relationship between soil series and site index of loblolly and shortleaf pine in Arkansas. Although he found that certain soil series usually produced pine of high site index, he concluded that height growth of the two species was affected more by several soil properties, including steepness of slope, depth to the B_1 horizon, and texture of the soil.

During the past 10 years, a number of publications and reports have indicated various degrees of success in correlating site productivity with soil series, types, and phases. Van Eck and Whiteside (1958) reported that they had found soil properties associated with change in site quality for red pine plantations in Michigan. They further stated that these properties are usually recognized in soil classification and that the soil-classification system should therefore form a basis for further interpretation efforts.

Broadfoot and Krinard (1959) found soil series and phases to be useful in predicting the site index of sweetgum in the lower Mississippi River Valley, although they cautioned about the possible range in variation of site index within a soil series. Chandler et al. (1943), Dean and Case (1959), Loftin et al. (1959), Ellerbe and Smith (1961), and Ritchie et al. (1961) have shown that the site index of tree species can be predicted from soil series, types, and phases. In fact, site-index information and other soil-woodland interpretations are now being included in some county reports of the National Cooperative Soil Survey.

In a study of the site index of black oak in Ohio, Carmean (1961) found that the site index had a greater variation within soil types than between the mean site-index values of the different soil types. His study also indicated pertinent soil properties that are related to site index and that can be used either in estimating site index directly or in modifying the present soil-classification system to gain more accurate site interpretations.

Gardner (1958) described the soil-vegetation associations in the redwood-Douglas-fir zone of California. He stated that natural vegetation is generally associated with soil series or higher category soil groups, but that the amount of vegetation or rate of growth is usually associated with within-series differences. Also in California, Zinke (1959) found that site index was not closely related to the soil series of the California soil-vegetation survey that he studied.

It is interesting to note that the best relationships of site index to soil units have been found in the Coastal Plain of the South where the topography is relatively gentle. And where hilly or mountainous topography is involved, these relationships are often not satisfactory.

However, this does not mean that the principle of interpretations through soil series, types, and phases is not good. On the contrary, these soil units may prove to be the best approach to site productivity and other interpretations, when and if certain obstacles are overcome in the classification of soils for forestry. Specifically, this means that we need more studies of variations within soil units as affected by topography, soil properties, and other environmental factors. Recognition of the significance of these factors may require modification of present soil units into additional units or phases, or it may mean that these factors will have to be retained separately and superimposed on present soil-survey units to attain reasonably accurate predictions of site index.

The importance of conducting soil-site studies on a more local geographic basis and on uniform parent materials is brought out rather clearly in Della-Bianca and Olson's (1961) recent work in the southeastern Piedmont. Most of the best soil-site relationships have been found in rather local areas and on fairly uniform parent materials (Trimble and Weitzman 1956; Doolittle 1957; Myers and Van Deusen 1960; Zinke 1959; Broadfoot and Krinard 1959; and Zahner 1958).

The classification of soils into series and types, and the establishment of phases, give assurance that the parent materials and other properties of each of these soil units and its environment will be more uniform than where all of the soils of a given area are considered at the same time. The soil unit then would seem to be an excellent place to start in conducting investigations of site productivity in relation to the soils and other environmental factors. Results from this approach to site studies would probably be more applicable to a larger geographic area than the usual approach to soil-site studies.

As indicated earlier, intensive investigations are especially needed on soils in hilly and mountainous terrain. However, a recent meeting (in Monroe, La., February 26–27, 1962), shows that there is also still a need for much site work in the Coastal Plains, the Piedmont, and other areas of gentle topography in the South.

The meeting at Monroe, La., attended by Forest Service and Soil Conservation Service personnel, dealt with problems of correlating site index with the various soils of the Gulf Coast States. The meeting was initiated by the Soil Conservation Service to consider differences found in site index assigned to the same soil units in different States and within States. The Forest Service was requested to assist through research in finding why these differences exist. Specific problems brought out at the meeting included the following:

1. What is the degree of variability of site index within soil series, types, and phases?
2. How can this variability be related to factors such as topography, climate, geographic location, and soil properties?
3. What methods can be used for refining soil series, types, and phases, and methods of grouping similar soils based on factors that research and survey have shown to be associated with similar tree-growth performance?

THE FUTURE IN SITE RESEARCH

Much of this discussion has been limited to soil-site research, and specifically to physical properties of the soil and other related environmental factors. This limited approach was taken mainly because so much of the practical value of site-quality information is based on recognizing soil series and types and on measuring certain physical properties of the soil and other factors of the environment.

Activities in site productivity fall into two broad groups: action programs and research programs. Obviously researchers should not be too deeply involved in an action program, but they do need to work on many research problems before and during an action program. This is what has happened in site-evaluation work in timber, and it is still going on, as evidenced by the recent joint meeting in Monroe, La.

The large-scale task of interpreting and mapping forest soils is the main action job in site-productivity work. The Soil Conservation Serv-

ice, the Forest Service (National Forests), universities, State groups, and others are conducting this work.

In site-productivity research, there are also two groups or levels of activities: applied research to help current action programs, and more basic research to probe the hows and whys of site problems that are bound up in complicated relationships of nutrition, water, temperature, energy, and soil-vegetation systems.

Soil-Site

As pointed out earlier, future research on soil-site relationships should be conducted on soils of the same or similar parent materials—preferably by groups of related soil series and types. And the possible limitation of size of the geographic area should be recognized.

There is a tremendous need for basic or intensive studies of soil properties, nutrition, water, microclimate, and energy as related to a single tree or to small stands of trees. Much work remains to be done on new techniques and methods for conducting these intensive studies.

It is important that we know more precisely the differences in productivity on the same soils for the different species. At present we have comparisons of site index for several eastern and western species on the same land (Copeland 1956; Doolittle 1958; Olson and Della-Bianca 1959; and Foster 1959). However, not only is this information far from complete, but it should be tied more closely to the soils and other site factors.

In soil-site research there are many problems related to more accurate expressions of productivity. For example, a species' height-over-age curve for each soil series[1] or groups of similar soils may be superior to the classic sheath of site curves covering many soils over broad geographic areas. Carmean (1956) and Spurr (1956) have demonstrated the need for site curves adapted to each soil or group of similar soils. And a more accurate expression of productivity—perhaps growth in cubic feet—in place of site index would be helpful.

There are vexing problems involved in sampling soil properties and vegetation on soil taxonomic units. Should soil units be sampled only at modal locations? What are the differences in soil properties and in site-index values between modal and nonmodal portions of a soil unit?

Total Site

Although in the past there have not been many proponents of low plants or other vegetation as ecological indicators of site productivity, there appears to be an increasing need in future site studies for measuring and analyzing low plant cover as well as the overstory trees.

An integrated system of soils, topography, climate, crop-tree data, and the lesser vegetation would appear to be especially useful in areas having young soils (recently glaciated), hilly or mountainous topography, and an extreme variability in soils. The different factors of the soils, topography, climate, and vegetation would be utilized together to classify and interpret sites.

[1] Suggested in a personal communication by Robert W. Wilson, Northeastern Forest Experiment Station.

USE AND MEASUREMENT OF SITE FACTORS AND SOIL PROPERTIES IN EVALUATION OF RANGE SITE POTENTIAL

James O. Klemmedson and Robert B. Murray[1]

Site is a well-established concept among ecologists and managers of wild-land areas, even though it has been loosely defined. "Site" in this paper is used in a sense approximately synonymous with "ecosystem," a term coined by Tansley (1935). Ecologists have frequently added to this concept, and the term is now more precisely defined (Jenny 1961; Odum 1959; Schultz 1960). Schultz (1960) says:

> An ecosystem is an area, of any size, in which organisms and nonliving substances interact and exchange materials. Actually, it is a three-dimensional area wherein the vertical aspect is most important, the horizontal aspect merely setting arbitrary side limits to the system. An ecosystem is open, that is, materials or energy can enter or leave the system, as well as circulate within it.

An ecosystem (or site, as used here) is not the same as a plant community, for ecosystem includes the entire environment, not just the vegetation.

STATUS OF RANGE SITE EVALUATION

During the past 2 or 3 decades, range scientists (Hull 1939) have expressed the need for greater

[1] The authors gratefully acknowledge the assistance of H. S. Crawford, Southern Forest Experiment Station, who reviewed the literature, and M. Hironaka, University of Idaho, who reviewed the manuscript and gave numerous helpful suggestions.

attention to soils in research and management of rangelands. The response has been significant, primarily in the form of soil-vegetation surveys (Anderson 1956; Gardner 1955). Soil-vegetation surveys have been made to obtain basic data on the nature of soils and vegetation, their relationships, and their distribution so that the data can be interpreted usefully for many purposes in the use and management of wild land (Gardner 1955). These surveys usually involve a characterization of the vegetation and soils of each unit of the landscape. Soils are described by a mapping unit (soil series, soil type, or phase of soil type) and referenced to the characteristic plant community found on that range site; the range site is described by a suitable name. These surveys have chiefly a utilitarian value and as such perform an important function in land management.

Evaluation of site seems to involve something different than soil-vegetation surveys. Webster defines *evaluation* as: "To ascertain the value or amount of; to appraise; . . . to express numerically." Range scientists appear to have done very little evaluation of range sites in terms of this definition. They need to know how one site relates to another, to what extent adjacent sites differ from one another, and why they differ. What is the influence on a site of repeated fire, or of 20 years of destructive grazing? To answer these questions the potential of range sites should be evaluated functionally in terms of site properties and/or site factors that condition properties of the site, regulate growth and disposition of precipitation, and influence land use.

In this paper, discussion is restricted to site evaluation in terms of growth potential; it considers which site factors and soil properties are likely to be most useful in evaluating site quality and how they can be measured.

OPPORTUNITY FOR USE OF FORESTERS' TECHNIQUES AND CONCEPTS

Foresters have been evaluating timber sites for several decades with much enthusiasm. Although they have made considerable progress, there has been a definite trend to develop more precise and more widely applicable techniques for evaluating site quality (Heiberg and White 1956). Foresters have found it increasingly necessary to link quality with specific properties and factors of the site. They have used mathematical and statistical models to enable the development of prediction equations of the general form,

$$Y=f(X_1, X_2 \dots X_n)$$

by which growth potential is functionally related to one or more independent variables (Carmean 1954; Doolittle 1957; Zahner 1958). Range scientists are only beginning to use this approach (Medin 1960; Van Dyne 1961; Van Dyne and Kittams 1960). Fortunately, however, foresters have already done much good work in site evaluation. This is not to say that foresters have the final answer, but their work has indicated what variables are likely to be most useful for site evaluation.

It matters not what kind of vegetation exists on the site, for the difference between any two sites, no matter how extreme, can be rationalized in terms of the intensity of one or more of the independent variables—according to the reasoning used by Jenny (1958). In accepting this thesis, range scientists need not rule out the use of techniques or concepts that have proved useful in evaluating forest sites. The principal difference between site evaluation in forest and range communities lies in the expression of productivity. Baker (1950) stated that "productivity of forest land . . . is most logically expressed in terms of productivity itself—the size of the crop that can be produced in a given time." However, foresters have found tree height at a given age to be the most suitable index to site productivity (Baker 1950). But what is the most suitable index to production of herbage or browse? This is one of the most difficult problems in range site evaluation and will be considered in a subsequent paper.

DIRECT AND INDIRECT CRITERIA FOR EVALUATING GROWTH POTENTIAL

The important physical factors of the environment that usually directly affect the growth and development of terrestrial plants are radiant energy, carbon dioxide and oxygen of the atmosphere, water, mineral nutrients, and temperature. Since these factors directly influence growth, they could be expected to be the most useful criteria for use in site evaluation. But for one or more reasons these growth factors have not been used.

Radiant energy and CO_2 content of the atmosphere are relatively constant, at least regionally, and therefore have little predictive value for macrosite studies. Temperature, perhaps the most easily measured of these factors, has been used infrequently, possibly because most site studies have not encompassed regions that have great temperature variation. Since water, mineral nutrients, and oxygen for roots are supplied by the soil environment, which is so variable from one point to another, they are the growth factors that have received the most attention in site evaluation studies. Unfortunately, however, they are not readily measured under field conditions, at least not in terms of the plant. For these reasons the

indirect approach to site evaluation has been used almost exclusively. Those site properties and site factors that are most closely related to the growth factors have been the most satisfactory indirect criteria for predicting growth potential.

Soil properties have been the most commonly used indirect criteria, but site factors also have been frequently used, often in the same study. Both groups of criteria are discussed in this paper. The distinction between soil properties and site factors needs some explanation at the outset. Knowledge of the relationship between these groups of criteria will enable better planning of studies and will enhance the interpretation of results.

1. *Site factors.*—As used in this paper, site factors are identical to the soil-forming factors recognized by most pedologists. The five soil-forming factors listed by Jenny (1941) are climate, organisms, topography, parent material, and time. These factors (actually groups of factors) define the state of the soil system. They regulate soil properties and *may* be treated as independent variables in functional analysis. Major (1951) rationalized that the same five factors define the vegetative system; hence, he refers to them as vegetation conditioning factors. Jenny (1958, 1961) recently has taken the next logical step and shown that these factors define the state of the ecosystem. He calls them "state factors." For simplification they are here referred to as "site factors."

2. *Site properties.*—Every system has characteristic properties. A site or ecosystem is characterized by the composition of its vegetation, the pH, color, nitrogen content of the soil, and other properties. These properties are functionally interrelated, but are dependent variables that are regulated or conditioned by the site factors climate (*cl*), organisms (*o*), topography (*r*), parent material (*p*), and time (*t*), as expressed in the following equation:

$$l=f(cl, o, r, p, t \dots).$$

This equation (interpreted from Jenny 1961) states that the magnitude of any property of the ecosystem (l) is determined by the site factors listed within the parentheses. This paper considers only the properties of the ecosystem concerned with the soil.

SITE FACTORS USEFUL IN SITE EVALUATION

Site factors have always been valuable in ecological studies, and they are almost invariably considered in site evaluation studies, directly or indirectly.

Topography

A brief review of the literature indicates that topography has been the site factor most frequently used in site quality studies. Widespread knowledge of the influence of topography on disposition of rainfall and on soil formation (Jenny 1941) is the primary reason.

Slope gradient.—Most authors (Anderson 1956; Einspahr and McComb 1951; Myers and Van Deusen 1960; Zahner 1958) find that as steepness of slope increases, productivity declines and the species composition changes. Increased slope gradient reduces infiltration of moisture and increases runoff and geologic erosion; the result is shallow, less mature soils—other factors being constant. This relationship profoundly influences site potential, for shallow soils have relatively lower nutrient and water-holding capacities.

Some authors have found the slope-site index relation to be nonsignificant (Medin 1960) or significant only under certain situations (Hill et al. 1948; Myers and Van Deusen 1960). Zinke (1958) found slope a significant indicator of site index when considered alone but nonsignificant when such variables as soil depth, distance to summer fog belt, and soil series were held constant. Such findings indicate the strong interrelation of these variables, particularly slope with depth.

Aspect.—In northern latitudes, timber and forage generally grow more luxuriantly on north and east aspects than on south and west aspects (Anderson 1956; Doolittle 1957; Einspahr and McComb 1951; Hill et al. 1948). North and east aspects are cooler and more mesic; hence, soil formation is normally advanced over comparable southwesterly slopes. Doolittle (1957) and Medin (1960) found aspect to be significantly related to site quality when considered alone, but nonsignificant in multivariate analysis. Doolittle attributed this to confounding of aspect with other variables such as depth of A horizon. The increased radiation on southwesterly slopes, although perhaps promoting more rapid growth when moisture is favorable, results in high evaporation and more droughty soils. Aspect is normally measured in degrees azimuth (Doolittle 1957). For regression analysis, Medin (1960) used sine of the azimuth clockwise from southeast, plus one.

Position on slope, shape of slope.—Range scientists and foresters (Anderson and Fly 1955; Baker 1950) have traditionally related characteristic vegetation with landform qualitatively, but have made little quantitative use of this important variable. Doolittle (1957) and Myers and Van Deusen (1960) found that position on slope (measured as percentage of distance from bot-

tom to top) was one of the two or three most reliable variables for estimating site quality. Medin (1960), however, found position on slope to be inferior to many other variables in predicting annual production of mountain mahogany (*Cercocarpus montanus*).

The shape of slope is seldom considered in site evaluation. Nevertheless, unmeasured extraneous variables such as length and shape of slope should be recognized to avoid confounding with other variables.[2]

Aandahl (1949) excellently characterized slope positions and landscape features in relation to soil formation. He showed how topographic features such as coves, spurs, knobs, and basins are distinguished by their slope curvature, and illustrated in detail how convex and concave vertical and horizontal curvatures may be measured and expressed mathematically. Doolittle (1957) measured shape of contour with a compass in degrees concave or convex.

Climate

The efforts of ecologists to relate vegetation to climate have been widely published, mostly with respect to species distribution (Anderson 1956; Daubenmire 1956; Heerwagen and Aandahl 1961) but also in regard to annual production of forage (Blaisdell 1958; Clements and Weaver 1924).

Foresters have made only limited use of precipitation data and practically no use of temperature records to predict site quality (Carmean 1954; Coile 1952; Zinke 1958), probably because of difficulties in obtaining reliable climatic data. They have clearly preferred to measure the influence of precipitation and temperature by other indirect variables such as depth, exchange capacity, and organic matter content of the soil, which are highly related and functionally dependent on precipitation. Jenny (1941) has assembled many of these soil property-climate functions.

Parent Material

Despite the widely recognized influence of parent material on soils and vegetation (Jenny 1941; Lutz 1958), this has been little used as a criterion for evaluation of site quality. Several researchers (Carmean 1956; Medin 1960; Myers and Van Deusen 1960; Zinke 1958) have segregated soil-site data by parent material groups and have found that parent material considerably influences site quality.

Many investigators use such a soil property as texture to express the influence of parent material (Doolittle 1957; Heerwagen and Aandahl 1961). Jenny (1941) and Lutz (1958) discuss relations between soil properties and parent material, but unfortunately they only generalize about these relations since most correlations obtained from the literature suffer from lack of control of the other soil-forming factors. A further obstacle to generalization about these relations is the fact that although we often treat parent materials as discrete variables, they are actually continuous and vary over wide limits within classes. This fact should be considered when parent material is used as a variable in site evaluation studies.

Acidic rocks such as granite, granodiorite, rhyolite, and gneisses and schists rich in quartz and orthoclase but deficient in plagioclase and ferromagnesian minerals generally yield infertile, coarse, and erosive soils (Lutz 1958; Retzer 1953). Granites weather more rapidly than rhyolite and weather to more productive soils (Lutz and Chandler 1946). Micaceous granites usually produce soils inferior to those from hornblende granites because mica weathers so much more slowly.

The basic rocks—basalt, andesite, gabbro, and diabase—generally produce fertile, dark, fine soils rich in calcium and phosphorus. Sites associated with basic rocks are usually good for exacting species (Lutz 1958).

Soils from ultrabasic rocks, notably serpentine and peridotite, are notoriously low in fertility. They are generally shallow and poorly supplied with essential nutrients (Walker 1954). Vegetation inhabitating serpentine soils is characterized by poor growth of forest trees and a flora rich in endemic species (Walker 1954).

Soils from sedimentary rocks may vary considerably in physical and chemical properties, depending on composition of the parent material. Limestone rocks characteristically exert a strong influence on the derived soils and vegetation (Lutz 1958), and the soils are normally quite fertile. Pure sandstones or arenites contain little or no argillaceous matrix; hence, they yield sandy soils of low fertility. Impure sandstones or wackes contain 10 percent or more argillaceous material and may yield reasonably good soils. Argillaceous rocks, including shales, mudstones, and siltstones, are also highly variable, resulting in soils shallow to deep and high to low in clay content.

Time

Time is hardly ever used as a specific factor in soil-site studies, even though it has an extremely important influence on site. This is because of

[2] Klemmedson, J. O. Influence of pedogenic factors in availability of nitrogen, sulfur, and phosphorus in forest and grassland soils of California. 1959. (Ph.D. thesis, Univ. of Calif. Library, Berkeley.)

the difficulty of measurement. Consequently, soil properties dependent on time are measured instead. As Jenny (1941) pointed out, in most systems of soil classification the time factor or degree of maturity plays the most important role. The San Joaquin family of soils in California is a good example of the classification of soils by age. In this chronosequence of soils, colloidal content in the A horizon varies from 0.83 percent in the youngest member to 7.0 percent in the older members. "The most drastic changes occur in the B horizon where, in the advanced stages, the clay accumulation gives rise to a reddish, indurated, impervious hardpan" (Jenny 1941).

The study of nitrogen and carbon in relation to the time sequence of mudflows of Mt. Shasta, Calif., (Dickson and Crocker 1953) and the sand dunes of Lake Michigan (Olson 1958) illustrates the impact of time on site productivity.

Organisms—The Biotic Factor

Soil scientists agree least about the function of organisms in the scheme of soil-forming factors. Their confusion probably arises from the dual role of vegetation as both a dependent and an independent variable. The logical clarification is expertly handled by Jenny (1941, 1958) and Major (1951).

Range ecologists have been primarily interested in vegetation as a dependent variable, and have usually considered it to be conditioned primarily by climate and edaphic factors (Billings 1951; Poulton 1959; Shantz 1938). Ecologists have shown little interest in the independent aspect of organisms with respect to their influence on range sites (Fireman and Hayward 1952; Zinke 1962). On the other hand, foresters have compiled extensive data on the influence of forest vegetation on such site characteristics as soil chemical status (Kittredge 1948; Lutz and Chandler 1946), soil physical characteristics, and susceptibility of sites to soil erosion (Kittredge 1948).

Other biotic subfactors such as microflora and microfauna, insects, rodents, wild and domestic grazing animals, and man have an important impact on ecosystems.

SOIL PROPERTIES USEFUL IN SITE EVALUATION

Physical Properties

Studies of soil-site and soil-plant relations, particularly in the United States, have emphasized the use of soil physical properties as criteria for predicting site quality (Coile 1952; Gessel and Cole 1958; Heerwagen and Aandahl 1961). These properties were most readily determined in the field. Also, many important timber species are commonly regarded as nonexacting in their requirements for soil nutrients (Lutz 1958). Particularly for these tree species, water is supposedly *the* most limiting growth factor. Since soil-water relations are primarily influenced by physical properties of the soil, the great emphasis placed on them by foresters is not surprising. Range scientists also have stressed physical properties in soil-plant relation studies.

Any soil property or site factor that regulates or is closely related to soil moisture or aeration may be expected to be correlated with site quality (Carmean 1954; Coile 1952; Gaiser 1951; Zahner 1958). White (1958a) emphatically maintains that available water is *the key factor* in forest site evaluation and says, that ". . . most workable classification schemes are, in effect, an attempt to estimate indirectly the soil moisture regime and, specifically, 'available water' for tree growth." Kozlowski (1955), Kramer (1949), and White (1958a) account for the difficulty of measuring water available to plants. Use of soil moisture and the problems of measuring it are discussed in a companion paper.

Depth

Total soil depth has probably been the most commonly used, and the most reliable, variable for site evaluation of both forest and range communities (Anderson 1956; Carmean 1954; Heerwagen 1958; Medin 1960; Myers and Van Deusen 1960; Retzer 1953). Soil depth is usually expressed as depth of the solum, depth to bedrock, depth to unconsolidated bedrock, or depth to C horizon. All of these depths are used in measuring the effective rooting zone, or the capacity of the site to furnish water and nutrients.

Depth of the A horizon (also expressed as thickness of topsoil, or depth to the subsoil) has been found to be closely correlated with site potential (Coile 1952; Coile and Schumacher 1953; Doolittle 1957; Zahner 1958). Doolittle (1957) found that depth of the A horizon alone accounted for 91 percent of the variation in site index. Depth of this horizon is likely to be the most reliable indicator of growth potential on heavy-textured, mature, or intrazonal soils likely to have compacted horizons that effectively restrict root growth or where moisture becomes excessive because of high water table or poor drainage. (Coile 1952; Garland et al. 1959; Kreis et al. 1956).

Measurement of soil depth, whether to the top of a given horizon or a restrictive zone, may be fairly easy or extremely difficult, depending on maturity of soil, kind of vegetation, and other factors. Effective depth of hardpan soils or of

those with water table conditions may be readily measured, whereas on deep immature soils supporting grasslands, or on young alluvial soils with herbaceous vegetation, effective depth may be quite difficult to determine (Gessel and Cole 1958). Soil horizon boundaries, like those of the so-called vegetation types, are arbitrary; hence, they are most easily interpreted by experienced soil scientists.

A particularly interesting problem is whether to sample for soil properties by horizons (i.e., A_1, A_2, B_1, etc.) or by depth classes (0 to 6 inches, 6 to 12 inches, etc.). Although sampling by horizons is generally preferred, depth classes have been used many times to good advantage (Aandahl 1949; Gates et al. 1956) and may even be preferable, especially in analysis of undifferentiated soils.

Texture

Soil texture, like depth, has been a useful index to productivity of range and forest sites (Heerwagen 1958; Retzer 1953; Zahner 1958). Medin (1960) found clay content of the A horizon second only to soil depth in accounting for variation in annual production of true mountain mahogany on sandstone parent material. Soil texture and relative stone content have long been used as indicators of relative fertility (Viro 1947; Yang and Lowe 1956).

Texture often has been expressed by textural class (i.e., sandy loam, loam, etc.) in site studies (Anderson 1956; Coile 1952; Hill et al. 1948; Retzer 1953) as determined by the "feel" technique. However, precision, reduction of sampling error, and quantitative expression for regression analysis can be achieved by laboratory determination. For most purposes the hydrometer method (Bouyoucos 1953; Day 1956) is sufficiently accurate. The coarse fraction (>2 mm. fraction) should be considered in expressing chemical and physical measurements for wild-land soils.

Bulk Density

Bulk density or volume weight of soils has been largely neglected in soil-site studies (Gessel and Cole 1958) although it has great utility. It has been used as an index to soil structure, permeability, aeration, and water-holding characteristics. Bulk density has been used to show the influence of biotic factors (Klemmedson 1956; Zinke 1962) on soil physical condition and to study the effect of soil compaction on the rooting characteristics of various plant species (Forristall and Gessel 1955; Fox et al. 1953).

The greatest utility of bulk density measurements for soil-site studies is probably in conversion of soil values from a weight basis to a volume basis and depth of water in inches (Gessel and Cole 1958). Soil moisture and nutrient data become more meaningful when expressed on a volume basis rather than by percentages, particularly where soil density differs greatly between sites. There is no universally satisfactory method by which to measure bulk density (Baver 1956; Lutz and Chandler 1946). Techniques using seamless cans (Andrews and Broadfoot 1958; Tanner et al. 1953) have been used extensively. Gessel and Cole (1958) report satisfactory results using an air pycnometer and lucite sampling ring, both developed by Wooldridge. A recent development, the nuclear density probe, promises to overcome some shortcomings of techniques now in use (Phillips et al. 1960). The particular conditions of a given study area will dictate the most satisfactory procedure. Stony soils, loose, gravelly soils, and soils with large roots present the most problems for undisturbed core sampling. In such soils, sampling by careful excavation and measurement of pits may be the best practice.

Drainage, Aeration, and Permeability

In soils where diffusion of gases and movement of water are restricted by fine subsoils, compact horizons, or a high water table, a deficiency of oxygen may stop root growth (Kramer and Kozlowski 1960). These conditions are commonly associated with regions of high precipitation, flat topography, and soils with clay subsoils. However, problems with entry and movement of air and water are not restricted to humid climates. Restricted drainage contributes to the salinization of soils on many arid ranges of the West and may involve low permeability of the soil or the presence of a high ground water table. Nonsaline sodic soils, having dispersed colloidal fractions, are notorious for restricted drainage.

Several measurements have been used to express drainage and permeability characteristics of soils. Depth to mottling (Barnes and Ralston 1955; Kreis et al. 1956), percent clay, or silt plus clay of the subsoil (Coile 1952; Zahner 1958), and imbibitional water value (Coile and Schumacher 1953; Zahner 1958)[3] are measurements that have been used to portray physical characteristics of subsoils as they regulate water movement, water retention, and aeration. These measurements may be especially applicable to site evaluation on range and meadow sites that have heavy soils and poor water relations. Qualitative classification of permeability (Aird and Stone 1955; U.S. Dept. Agr. 1951), surface drainage and subsoil characteristics that affect water movement such as plasticity, compactness, and structure (Coile 1952) have been used success-

[3] Metz, L. J. Relationship between soil properties and the growth of loblolly pine in the southeastern Coastal Plain. 1950. (Unpublished thesis on file at Duke University, Durham, N.C.)

fully in some soil-site studies and should be considered in range-site studies where applicable. Where quantification of variables is desired, permeability of soil may be determined in the laboratory (Steinbrenner 1951; U.S. Salinity Laboratory 1954).

Chemical Properties

Experience in use of soil chemical properties in studying range-site potential is so limited (Medin 1960; Van Dyne 1961; Van Dyne and Kittams 1960) that no clear indication of the most suitable variables is apparent. Even so, the chemical characteristics that appear to offer the most promise as criteria are nitrogen, organic carbon (organic matter), phosphorus, sulfur, exchange capacity, and certain properties associated with salt-affected soils.

Since nitrogen, sulfur, and organic carbon are closely associated with the organic fraction of soils (Jordan and Reisenauer 1957) and are therefore distributed in the upper soil horizons, these elements are especially vulnerable to loss by erosion on deteriorating ranges (Craddock and Pearse 1938; Haupt 1956). Measurement of these properties may provide clues to changes in site potential resulting from erosion and site deterioration. As organic carbon, nitrogen, phosphorus, and sulfur have been shown to vary with temperature, precipitation, and parent material (Martin 1958),[4, 5] these nutrients can be expected to vary greatly from one environment to another.

On arid ranges, amounts of soluble salts and exchangeable sodium often reach levels that are detrimental to growth of plants. Several studies have shown that the distribution pattern of much desert vegetation is associated with the concentration of soluble salts, exchangeable sodium, and related soil conditions (Gates et al. 1956; Shantz 1938). For site-potential studies in these regions, electrical conductivity of the saturation extract, exchangeable sodium percentage, and other measurements appropriate for salt-affected soils (U.S. Salinity Laboratory 1954) should be considered.

For ranges in humid and semihumid climates, the work of foresters may be consulted. Chemical properties most frequently used by foresters are total nitrogen, organic matter, available phosphorus, exchange capacity, and exchangeable bases (Coile 1952; Forristall and Gessel 1955; Hicock et al. 1931; Leaf 1956; Mader and Owen 1961; Pawluk and Arneman 1961; Tarrant 1949; Voigt et al. 1957).

[4] Harradine, F. Factors influencing the organic carbon and nitrogen content of California soils. 1954 (Ph.D. thesis, Univ. of Calif. Library, Berkeley.)

[5] See footnote 2.

Problems in Using Chemical Data

A discussion of problems involved in the use of chemical data in site evaluation may be more pertinent than suggestion of techniques for measurement and discussion of detailed procedures explained elsewhere (Forest Soils Committee of the Douglas-Fir Region 1953; Jackson 1958; U.S. Salinity Laboratory 1954).

We may speculate about the reasons for lack of more use of chemical data in soil-site studies, and may thus arrive at some of the problems that should be considered in their use. Despite our understanding of the theoretical roles played by various phenomena in plant growth, we tend to interpret results of our investigations so that a few factors are emphasized to the exclusion of all others. This seems to be true for soil-site studies where physical properties have been stressed. Voigt (1958) points out, however, that growth responses attributed to one variable often reflect influence of other variables. For example, soil depth, texture, and organic matter content have been used as indirect measures of both water and nutrient capacity. Voigt (1958) states further:

> While no one can deny the sometimes paramount importance of soil moisture in tree growth, it should be appreciated that the level of available nutrient elements also exerts a very positive influence. In a natural soil system, the factors which regulate the supply of available water are often the same as those which regulate or are related to the supply of available nutrients.

Failure to show a relation between chemical properties and tree growth has been attributed to essentially similar levels of inherent fertility (Voigt 1958) or inherently high fertility across all sites studied (Tarrant 1949). White (1958a) explained that only in situations of acute nutrient deficiency would chemical criteria likely evaluate site accurately. However, White did not go far enough, for as Voigt (1958) has pointed out, some variation in the variable in question is also necessary for significant results.

Voigt (1958) points out that chemical methods are normally more sensitive than physical measurements; this fact combined with the natural variability of forest soils may be responsible for some of the confusion in use of chemical data. Studies by Harradine (1954), Zinke (1962), and Zinke and Crocker (1962) have shown the magnitude to which soil properties vary spatially under the influence of forest trees. Most range soils are reasonably uniform within short distances; others are as variable as forest soils, particularly those soils whose site factors represent extreme conditions. For example, Fireman and Hayward (1952) found distinctive distribution patterns for exchangeable sodium under *Sarcobatus vermiculatus* and *Artemisia tridentata*. Thus, where soils are highly variable, close atten-

tion to the spatial distribution of soil properties and site factors appears to be a must in sampling for functional analysis of sites (Harradine 1954; Klemmedson 1959).

Much of the past failure of chemical criteria may be attributed to inability to measure adequately the nutrient-supplying capacity of soils. Although some investigators have found significant relations between growth capacity and nutrients when the latter were expressed as total or exchangeable amounts, this procedure usually yields only fair results. Agronomists generally have found these measurements inadequate for agricultural soils and are striving for better measurement of available nutrients.

Nearly all the present methods of chemical analysis were developed for agricultural crops. Extracting reagents in current use are only approximations of the average soil solution for agricultural soils and may bear even less relation to the true situation for wild-land soils (Voigt 1958). The level of available inorganic ions in the soil strikingly affects mycorrhizal formation (Hacskaylo 1959) and the nitrogen fixing activities of *Rhizobium* (Black 1957). Hence, in forest and range ecosystems where these symbiotic relations are common, even the best expressions for availability of soil nutrients in agricultural soils may be unsatisfactory indices of growth potential (Wilde 1958). Despite these obstacles, availability of nutrients, as measured by a variety of fertility tests, can be expected to be more useful criteria for predicting site potential than total amounts of the nutrient.

Measurement of Nutrient Availability

Procedures for assessing the fertility status of nutrients, i.e., determination of the available nutrients or supplying power of soils for nutrients, may be divided into two groups: (1) Chemical methods and (2) biological methods wherein the growth response of an organism is observed or absorption of the nutrient element is measured.

Chemical methods.—In chemical methods the nutrient element in question is extracted by a suitable reagent and chemically determined in the extract. Only the relative amount of available nutrient may be determined, but with suitable biological calibration, many such procedures have been used by agronomists to predict whether fertilizing is warranted for agricultural crops.

Use of water extracts is best adapted for components of the soil that are completely soluble, such as nitrate. Hence, several procedures for predicting nitrogen availability use water extracts and nitrate analysis. The nitrate production procedures under development by Iowa researchers (Fitts et al. 1953; Munson and Stanford 1955; Stanford and Hanway 1955) and others (Eagle and Matthews 1958) are better than earlier methods (Black 1957) and may be useful in range-site evaluation. Water extracts also have been used to determine the fertility status of less soluble nutrients. The "Bingham phosphate test" (Bingham 1949), which has been successful on neutral soils of California, is of particular interest since it is doubtful that much of the available soil phosphorus is in the water-soluble form.[6]

A wide variety of other extractants, including solutions of strong and weak acids and neutral salts, has been used to estimate the soluble plus exchangeable cations. Solutions of strong and weak acids have been particularly useful in estimating phosphorus availability for acid soils (Black 1957; Nelson et al. 1953), but they are obviously unsatisfactory for calcareous soils.[6] Black (1957) ably discusses phosphorus availability to plants and evaluates various methods for its estimation.

The degree of saturation in the exchange complex is often assumed to be an index to the availability of nutrient cations. However, there are severe limitations to this concept. The availability of cations adsorbed on clay depends on at least four factors;[6] all four should be considered in estimating availability. These factors are (1) degree of saturation, (2) nature of complementary ions, (3) type of colloid and its exchange capacity, and (4) kind of plant. Soil potassium, although normally in adequate supply in western range soils, is the nutrient cation of principal interest. Although measurement of exchangeable potassium presents special problems, owing to the somewhat complex chemistry of soil potassium, many investigators who have chosen to measure exchangeable potassium as an index to supplying power have obtained satisfactory correlations with potassium absorbed by field or greenhouse crops (Black 1957).

Biological methods.—A wide variety of empirical tests has been employed by European and American scientists to assay soils biologically for supplying power of nutrients. As with the chemical methods, there are several limitations (Millar 1955), especially time and extrapolation of results to field problems. However, results of biological tests, especially from pot tests, are usually readily accepted and commonly used as standards of comparison for chemical methods (Nelson et al. 1953; Vandecaveye 1948). Many researchers (Eckert and Bleak 1960; Klemmedson 1959; Mitchell 1934; Richards 1959; Wagle and Vlamis 1961; Vlamis et al. 1959) have found the pot culture technique quite useful in investigations of fertility of range and forest soils.

[6] Babcock, K. L. The soil as a medium for plant growth. Univ. of Calif. Dept. of Soils and Plant Nutrition, Berkeley. (An undated processed syllabus.)

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In pot culture methods, soil samples are planted with a standard crop, and the response to various combinations and rates of applied nutrients is measured. Several procedures have employed the same basic principles (Jenny et al. 1950; Millar 1955; Mitchell 1934; Nearpass et al. 1961). Through the use of suitable indices, relative supplying power for specific nutrients may be calculated. Dos Santos et al. (1960) and Nelson et al. (1953) discuss the relative merits of the most commonly used indices, particularly their suitability as indicators of soil phosphorus availability.

Even where successful, pot culture methods are expensive and time consuming. Extensive greenhouse space must be available, and extension to more than a few nutrients often involves prohibitive space demands. Hull's (1939) view that greenhouse pot tests have only doubtful value in measuring site differences of rangelands because field conditions are not evaluated is a common criticism of these methods. However, pot culture tests are intended to portray the relative nutrient status of soils under standard conditions and not under climatic and other influences. Results from these tests should be interpreted with these points in mind. Extrapolation of laboratory results to the field is difficult, particularly when diverse wild-land areas are involved, for the influence of climatic and biotic factors also must be considered.

Foliar analysis or plant analysis is a modern technique used by agriculturists, horticulturists, and more recently foresters, for detecting nutrient deficiencies and determining fertility of soils. Except in limited research, range scientists have not resorted to plant analysis for determining fertilizer needs or for evaluating sites. As expected with any new technique, there are conflicting reports as to the value of plant analysis in detecting relative fertility of forest soils. Several attempts have been made to correlate mineral content of foliage with forest site quality (White 1958b). Investigators who have worked on depleted soils where nutrient deficiency was apparent have been the most successful.

In Sweden, Tamm (1956) suggests that foliar analysis is superior to soil analysis, but Viro (1961), in a study of soils from Scandinavian and other European countries, found that soil analysis gave more reliable results regarding nutrient availability. In a discussion of the limitations of both plant and soil analyses with respect to silvicultural practice, Wilde (1958) made conclusions similar to Viro's. Although techniques of plant analyses involve difficulties in sampling and interpretation (White 1958b), the methods are promising and should be investigated for possible use in range research in view of the advantage of determining nutrient availability under field conditions.

Two other methods, the Neubauer test and microbiological tests, should be mentioned. In the Neubauer test (Millar 1955) a small sample of soil is extensively cropped so that available nutrients are exhausted. Chemical analysis of the crop shows the amounts of available nutrients. Despite some limitations, the Neubauer method has proved a useful research tool in fertility studies of potassium and phosphorus.[7]

The premise in using micro-organisms as a measure of nutrient level is that their requirements are much the same as those of higher plants. Because micro-organisms grow more rapidly than standard crop plants, their use requires less space, time, and work. *Azotobacter* sp. and *Aspergillus niger* (Millar 1955; Nowosielski 1960) have been commonly used. More recently, Tchan et al. (1960) reports good results with soil algae.

CONCLUSION

Studies of soil-plant relations have partially satisfied a demand for greater attention to soils in research on and management of rangelands. However, we need to evaluate the potential of sites functionally to enable the assembling of knowledge about sites in terms of curves and equations. This approach to study of range sites will enhance our ability to predict the potential of sites, to gain insight into causal relations, and to facilitate our basic understanding of range ecosystems.

Foresters have done good work in site evaluation. Many techniques and criteria they have used in relating timber production to specific properties and factors of site are directly applicable to range-site evaluation. In this paper, various site factors and soil properties that appear to offer the most promise as criteria for prediction of range-site potential have been reviewed. Success in site-potential studies depends upon the ability to measure pertinent growth factors.

Growth factors supplied by the soil—water, mineral nutrients, and oxygen for roots—are direct criteria and have the greatest utility for site evaluation; however, they are quite difficult to measure. Therefore, scientists have resorted to measurement of indirect criteria. Of these criteria, soil physical properties and site factors that are highly related to soil moisture have been the most useful. Soil chemical properties have been used less.

The authors have not attempted to suggest which criteria or combination of criteria should be used in site studies. Selection of these criteria

[7] See footnote 6.

obviously must depend on many considerations related to the individual study. By the same token, we have not indicated *the* best method for measurement of the various soil properties and site factors, for no single method is best for all studies. Choice of method for measurement of a particular nutrient or physical property usually depends upon local conditions.

The adequacy of any site evaluation study depends upon the ability of the investigators to select criteria that most closely measure the level of available growth factors for the area in question. Improvement in these studies will come with selection of more *effective* criteria and measurement of growth factors as plants or plant communities utilize them.

PRODUCTION AND FLORISTIC COMPOSITION OF VEGETATION AS MEASURES OF SITE POTENTIAL

Richard S. Driscoll

Site measurement, evaluation, or classification requires investigations of both synecological and autecological factors. To do this, it must be assumed that the total vegetational matrix comprises the plant community and that this community can be measured and classified into a usable entity.

Several concepts and numerous terms have been proposed as the science of plant communities has evolved. As a result, apparent discord has developed concerning community interpretation and terminology. To facilitate better understanding, the following definitions of concepts and terms are suggested.

THE CONCEPT OF SITE

What is a site? Is it a particular landform, kind of soil, or neither? Most workers agree that a *site* is where a certain kind of plant community is found.

A *plant community* is an aggregation of plants having mutual relationships among themselves and with their environment. It is either concrete, the specific example in mind, or abstract, the synthesized example of many concrete communities (Oosting 1956). A *climax community* is one representing a time phase of great stability in which successional causes cannot be observed and the future cannot be predicted (Selander 1952). Even if successional causes can be observed, if there is evidence of self-perpetuation, no evidence of replacement by a different community, and no possibility of predicting future succession, the community may still be considered climax.

Thus, the location of a climax community or a seral stage of that community is the *habitat* or *site* which represents a multidimensional place in space containing sufficient energy and matter derived from biotic and abiotic sources to support and maintain that community (Davis 1960). The combined result of the community and its physical habitat or site constitutes the *ecosystem*, an ecological unit containing organic and inorganic components in relatively stable dynamic equilibrium (Tansley 1935).

The ecosystem is a dynamic entity, and its basic structure changes when catastrophies such as flooding, diastrophism, vulcanism, or major climatic changes provide major, long-lasting alterations in the physical site. Thus, vegetation in a transitional stage of secondary succession should be considered only a temporary occupant of the site and component of the ecosystem since it is not maximizing the effective energy available to the site (Oosting 1956).

Succession after disturbance will probably not result in the same vegetational matrix as existed under pristine conditions. This is part of the dynamism of community structure and development—even the abstract community described under pristine conditions does not exist precisely. However, recognition and description of climax, when such situations can be found, is a useful point of reference for effective land management.

It is impractical and probably impossible for anyone to completely evaluate ecosystems or sites. Vegetation is probabaly the best integrated measure of site, although Billings (1952) lists 17 factors and 43 factor subdivisions in his discussion of the holocoenotic environment as needing study in ecosystem classification. Lack of time, manpower, and suitable instruments limit the factors that can be investigated. However, classification can be accomplished if it is based on impartial and critical analysis of quantitative measurements of selected characteristics. This situation is exemplified by recent studies by

Daubenmire (1952) and Driscoll, Dyrness, Eckert, and Poulton.[1]

A recent symposium on forest types and forest ecosystems indicated a need for ecologists to attain some common understanding on how vegetation could and should be classified (Society of Forestry in Finland 1960). Such understanding would allow more valid comparisons among research findings and provide insight on maximum land utilization.

THE CONCEPT OF POTENTIAL

"Potential" is a nebulous term, and it is meaningless without certain provisions. Specifically, potential means possible or latent functions. The term is similar to quality as both must be predicated to a specific object or use. Consequently, a site or ecosystem should be characterized according to potential or quality and should specify certain objectives. The evaluation of site must answer such questions as, "Is the site best for wildlife, livestock, timber, watershed, recreation, or a combination of these uses?"

Generally, potential or quality denotes some standard of excellence which characterizes the use of an item for some particular purpose. Consequently, several levels of potential or quality are possible for any site, but high quality does not necessarily mean high value for a particular use. For example, Driscoll[2] pointed out that the status of various undisturbed ecosystems in the central Oregon Juniper zone varies, depending on the use considered for each entity. Ecologically, the ecosystems described represent top potential since the vegetational matrices appear to be making maximum utilization of available energy. Conversely, the grazing potential or quality of each unit will vary according to the kind of animal using it. Those ecosystems in which the vegetational component is characterized by a dominance of antelope bitterbrush (*Purshia tridentata* (Pursh) DC.) are more valuable for deer than for cattle.

In addition to forage availability and preference, the value of a site must be based on seasonal aspects of use, its ability to provide cover and food for herbivorous animals, and the economic aspects of other uses in comparison to grazing or browsing. Use of a site or sites by wildlife illustrates the complexities of evaluating site potential. Several sets of indices must be developed: Summer food potential, winter food potential, summer need for openings, and winter need for cover. Winter food and cover potentials are related since food requirements vary with protection from cold and wind. These indices can be combined into a meaningful expression for each site or combination of sites according to seasonal use patterns. They also will provide guides for estimating capabilities of animal production.

Thus, evaluation of site potential should include: (1) The natural successional changes which might occur if the resource were to no longer be managed by man, (2) the influence that a specified use and management by man would have on altering natural succession, and (3) the time interval which must be established so that hypotheses become realities instead of abstractions.

COMMUNITY EVOLUTION

Plants are living organisms. They grow as a result of selective action of environment operating as a sieve on genetic variations, the origins of which are strictly matters of chance. The element of chance is by no means minor. The probability of species to become established at a certain place is governed by the vagaries of history, by local and surrounding site conditions, by the ecological tolerance of the species, and particularly by the presence or absence of germules of the species.

Not all species and probably not all ecotypes have the same ecological tolerance (Daubenmire 1959). Some species are adapted to a wide range of conditions, others to a narrow range. Thus, there is an overlapping of species ranges. Very seldom, under natural conditions, does a single species completely occupy a specific habitat to the exclusion of all other species. Without intensive control, single species do not and cannot utilize all the environmental potential of a site. Thus, plant communities are formed in which, under natural conditions, a dynamic cycle is established whereby replacement equals death. In this sense, Plochmann (1956) proposed three alternating structures of communities: A young phase, an optimal phase, and an aging phase.

The plant community is a complex system consisting of numerous parts, each contributing to or detracting from the well-being of the others so that harmony is introduced. Physically, each

[1] Driscoll, Richard S. Characteristics of some vegetation-soil units in the Juniper Zone in central Oregon. 150 pp. 1962. (Ph.D. dissertation on file Oreg. State Univ., Corvallis.)

Dyrness, Christen T. Soil-vegetation relationships within the ponderosa pine type in the central Oregon pumice region. 217 pp. 1960. (Ph.D. dissertation on file Oreg. State Univ., Corvallis.)

Eckert, Richard Edgar, Jr. Vegetation-soil relationships in some *Artemisia* types in northern Harney and Lake Counties, Oregon. 208 pp. 1957. (Ph.D. dissertation on file Oreg. State Univ., Corvallis.)

Poulton, Charles E. Ecology of the non-forested vegetation in Umatilla and Morrow Counties, Oregon. 166 pp. 1955. (On file Wash. State Univ., Pullman.)

[2] Driscoll, Richard S. Characteristics of some vegetation-soil units in the Juniper Zone in central Oregon. 150 pp. 1962. (Ph.D. dissertation on file Oreg. State Univ., Corvallis.)

type of community has an inherent spectrum of toleration to normal extremes of adverse conditions to which it is subjected (Allee et al. 1949). As a result, the community at certain stages is a good measure of a site since its components represent the ability of the total community to convert existing environmental factors into plant tissue. The problem is choosing the attribute or attributes of the community which best measure the ability of the site to produce.

PRODUCTION AS A MEASURE OF SITE

Production seems the best single dimension by which species may be ranked according to functional significance in the community (Whittaker 1961). It provides effective approaches to relative dominance, species diversity, and other aspects of community analysis. Production establishes a base for evaluating the grazing capacity of range units and serves as a component in the evaluation of ranch or range property. Forage yields typify the community and are tied directly to animal output and rancher income (Costello 1956). Thus, production can be used as a single factor in site evaluation if sufficient knowledge of the species in the community is available.

Methods

Production implies synthesis with a resultant increase in weight and is determined by various estimating or clipping techniques. Methods of measuring production were reviewed extensively by Brown (1954) and at a recent Forest Service symposium (U.S. Forest Service 1959). Most techniques provide estimates of weight of plant material on a unit-area basis. The size and shape of plots and sampling intensity depend on the purpose of the measurement and the kind of vegetation. Methods for estimating yields are grouped under three broad categories: (1) Estimating *in situ* in the field, (2) cutting and weighing samples of herbage from known areas at appropriate intervals, and (3) using the grazing animal to measure either animal production or amount of herbage consumed and digested.

Effect of Weather

Vegetational production is a useful indicator. However, there are serious difficulties in obtaining data, and, once available, interpretation problems exist. Production, like the plant community, is dynamic, but it is more so since it is strongly dependent on weather. In central Utah, for example, vertical distribution of forage weight along the height of the stem of each of 10 species showed inconsistency during a 4-year period (Clark 1945). Also, growth form for samples from the same species varied, depending on year, elevation, and site. Harris (1954) found that utilization of key forage plants in the Blue Mountains of eastern Oregon varied greatly among years as a result of highly fluctuating forage production. Similarly, other studies have shown high fluctuations of forage production due to seasonal climatic differences (Blaisdell 1958; Driscoll 1955; Paulsen and Ares 1961; Passey and Hugie 1962; Odum 1960).

Discrepancies

Many examples support the use of production to characterize sites, explain responses to treatment, or identify secondary successional stages. Eckert [3] used production as one of many ecosystem attributes to characterize some sagebrush (*Artemisia* spp.) types in the Oregon High Desert. Heerwagen (1958) separated three sites on the basis of significant differences in herbage yields. Hurd and Kissinger (1952) showed differences between sites and between protected versus grazed areas on the same sites. Passey and Hugie (1962) showed differences in production among ungrazed native range areas. Evanko and Peterson (1955) and Bentley (1950) explained differences in grazing capacity and grazing treatment on the basis of production. Others have used production to separate sites, evaluate treatment effects, or identify successional patterns (Goebel and Cook 1960; Pase 1958; Humphrey 1949; Cook et al. 1958; Strickler 1961).

There is some evidence, however, that production is not a reliable tool for evaluating sites. Box (1960) found that total yearly production was very similar for three of four plant communities in south Texas. He separated communities (the vegetational component of specific (ecocystems) on the basis of floristic composition, plant density, cover, frequency, and abundance (Box 1961). Likewise, in two different ecosystems in South Carolina, Odum (1960) found that total annual production was very similar but that the distribution of productivity among species was different.

The apparent discord in the use of production to evaluate sites emphasizes two important factors: (1) Two investigators cannot view the site identically and (2) production cannot be the only measure of the site. Three additional and important factors are evident: (1) Production

[3] Eckert, Richard Edgar, Jr. Vegetation-soil relationships in some *Artemisia* types in northern Harney and Lake Counties, Oregon. 208 pp. 1957. (Ph.D. dissertation on file Oreg. State Univ., Corvallis.)

values and measurement methods are rare for communities containing woody species, (2) research results involving production data do not qualify use according to local conditions or specific needs, and (3) production has rarely been derived for several specific points in the successional pattern or referenced to other communities in terms of quality.

Simple production figures, either total or by species, are of little value unless they are referred to a specific use. What if one site produces five times as much plant material as another? If the amount of herbage and forage contributed by each species is not known, optimum use and ordination of the site is unlikely.

To realistically evaluate sites, total production, not merely production of herbs and perhaps shrubs, must be considered. Where trees are present, basing results only on production data of grasses, herbs, and perhaps shrubs can very easily provide erroneous site evaluation and characterization. The complexity of structure and size of plants in forest and shrub ecosystems renders such research difficult but not impossible, as indicated by the work of Burger (1953), Ovington (1957), Ovington and Madgwick (1959), and Whittaker (1961). If production is to be used as a site measurement, arboreal production must be included.

The point of reference from which sites are classified has largely been ignored. Most current concepts use climax or pristine conditions to relegate various condition classes (Humphrey 1949; Stoddart and Smith 1955; Dyksterhuis 1949). Few workers have related condition, and hence production, to the kind of animal, to season of use, or to the possibility that some situation other than climax might be more productive. One concept, ". . . the relative position of a range with respect to its potential as determined by climate and soil under long-time proper grazing," meets these stipulations most closely (Society of American Foresters 1955).

Vegetational production of an ecosystem is not always greatest in climax situations. Weaver (1924) showed that production is directly proportional to available water content in the soil and inversely proportional to evaporating power of the air. Thus, site quality in terms of total vegetational production, without reference to use, increases as water become more available and evaporation decreases. In addition, Oosting (1956) points out that succession progresses from fractional utilization to maximum utilization of the effective environment of the site. Thus, it should be inferred that the greatest production occurs in climax situations. However, the opposite is more likely.

Effect of Succession and Removal

Clements and Shelford (1939) stated that both plant and animal production is greater in subclimax (or a seral stage) than in climax, except possibly for grasslands. Plochmann (1956), Rowe (1961), and Linteau (1955) also recognized that total forest productivity was less at climax than at some successional stage. Odum's study (1960) of old-field succession showed that total productivity does not necessarily increase with succession. Other studies have shown that intraspecific and interspecific competition in the absence of grazing or some other disturbance have adverse effects. The accumulation of dead residue around the crowns of some plants, particularly grasses, reduces herbage production (Wahlenberg et al. 1939; Ehrenreich 1959; Duvall 1962). Removing some of this residue by grazing or burning apparently increases herbage production. Grazing of some shrubs also increases production of usable herbage (Garrison 1953).

To conclude, production can be used, with certain reservations, to classify site potential. Potential must be qualified with respect to the kinds of uses contemplated, and the point of reference must be ascertained since climax situations may not represent the highest productive capacity for the site. Australians, working with pastures as well as with natural plant communities, have shown conclusively that optimal leaf areas exist for plant communities beyond which production is reduced (Blackman and Wilson 1951; Brougham 1958; Blackman and Black 1959). There is an optimum ratio of leaf area to ground surface (leaf-area index) for the maximum exploitation of the incoming radiation. Once this optimal level is surpassed, production stagnates or decreases.

Energy Relationships

Little attention has been devoted to the energy relationships and consequent energy production of plant communities in specific ecosystems. In any region, vegetation reaches a dynamic equilibrium when there is maximum exploitation of incoming radiation to produce the greatest amount of dry matter. The optimal utilization of solar radiation will not occur unless there is maximum absorption by the leaves, and this is linked to the leaf-area index and the duration of the green-leaf period.

Perhaps site potential could be established from the energy utilization and production standpoint. Some pioneering has been done on this aspect. For example, Long (1934) and Golley (1961) found that energy values of vegetation

varied between plant parts, months of a year, dominant vegetation in ecological communities, light intensity, length of day, and kind of soil. Efficiency of utilization of incoming solar radiation can be estimated for species and communities from data on total incoming solar radiation and energy released on the complete combustion of dry matter (Ovington 1956; Ovington and Heitkamp 1960). At Bedgebury, England, Ovington and Heitkamp (1960) estimated the efficiency of a species of spruce (*Picea amorika*) at 2.7 percent according to the equation:

$$\text{Efficiency} = \frac{\text{Caloric value of vegetation/unit area}}{\text{Net amount of radiation available/unit area (calories)}}$$

Quality or potential of ecosystems or sites might also be oriented to the ability of the plant community to provide energy and nutrients to the grazing animal. Tons of vegetation may be produced, but it is of little value if the grazing animal cannot utilize it after ingestion. Volumes of research results are available; these data indicate the palatability, chemical composition, and digestibility of pasture forages, and the interrelations of these factors. For example, Plice (1952) found that increased carbohydrate content increased the preference shown for various plants.

Albrecht (1945) reported that increased protein and phosphorus resulting from fertilization increased the palatbility and consequently the quality of forage. Cook (1959) showed that site definitely influenced the palatbility and nutritive content of seeded wheatgrasses. Information is available for determining the digestibility of forage and relating it to animal production (Lofgreen 1951; Cook et al. 1952; Maynard and Loosli 1956). Perhaps value to the animal should be the final determinant of site potential from the production standpoint.

FLORISTIC COMPOSITION AS A MEASURE OF SITE

Floristic composition is a synthetic measure of vegetation referring to the relative amounts of species within a community; it is usually expressed as a percentage of the total vegetation. The attribute can be determined from various quantitative and qualitative measurements and may vary within a community at a given time, depending on the measurement method used. For example, Goebel and Cook (1960) based composition of good, fair, and poor forage species on ground surface area covered with herbage. Computing composition from their production data alters the relative importance of the three forage classes and could conceivably alter the notion of site potential.

Its Usefulness

Floristic composition can be useful for evaluating sites if enough is known regarding the ecology and physiology of the species and communities and their possible uses. It has value for indicating the inherent capacity for natural change by evaluating the successional status of a community. Composition can indicate the kind of community which might develop under a given management and climate. It can also indicate potential for some other use such as production of seeded forage species, timber, or conversion to a particular cultivated crop.

Floristic composition is also an index to various site conditions; these include:

1. The stabilizing effect of vegetation on the soil.
2. The competitive relations within a stand.
3. The degree of openness within a stand.
4. The degree of control various species have over the stand.

The success of floristic composition indexes in these situations depends on what is known about the area.

Its Limitations

Conflicting results place doubt on the use of floristic composition to evaluate sites or effects of treatment. Some investigators reported that any disturbance interfering with growing conditions of the plant community changed the floristic composition (Klemmedson 1956; Short and Woolfolk 1956; Stewart et al. 1940). Others have found little change in composition, based on area covered, for deteriorating ranges (Hanson 1951; Costello and Turner 1941; Ingram 1931).

Composition within a community on a specific site may also change without disturbance created by man. Growing conditions vary, and differences in the genetics among species or genera induced by evolution create differential responses to growing conditions. This has been verified by Passey and Hugie (1962), who found that after 4 years of observation in sagebrush-bunchgrass range, species composition based on herbage production varied considerably from year to year.

As with production, the point of reference from which to classify sites on the basis of floristic composition has not been completely defined. Some evidence indicates that some seral stage

might be a better point of reference than the climax (Rowe 1961; Plochmann 1956; Linteau 1955; Clements and Shelford 1939). Composition has been used to separate sites, but it has given no indication of the relative potential of the units (Marquiss and Lang 1959; Beetle 1952).

In view of conflicting evidence, and because ecological and physiological information on species and communities is scanty, floristic composition must be used with other community attributes to evaluate sites. Local conditions and specific needs will control site or ecosystem evaluation regardless of the vegetational attributes used.

RESEARCH NEEDS

Any unit of measure adopted to evaluate sites must be translated so that the data obtained can be used by each group concerned. Animal husbandmen and economists, for example, need the data as much as ranchers and range managers. The unit or units selected should permit understanding of the effects on animals from grazing and digestion of forage.

The suggested areas of investigation that follow are not necessarily arranged according to priority. They are designed to provide criteria to realistically evaluate sites.

1. *Ecological studies of ecosystems to isolate and define biotic and abiotic factors useful for local classification and which might also be used universally for this purpose.* Research in this area should strive to define basic ecological units in an unbiased manner so that all possible uses can be evaluated even though a single use may hold immediate importance. Production and floristic composition are quantitative and qualitative attributes of the biota, and such research would determine the degree to which certain circumstances should limit the use of these attributes for defining the potential of sites.

2. *Determination of the ecological and physiological responses of species and communities to use in expression of changes in production and floristic composition.* The primary objective would be to determine when and under what conditions species and communities produce the maximum usable vegetation for specific purposes. The results would provide management with a basis for utilizing the full potential of sites once this capacity was defined.

3. *Measurement of the energy relations of sites or ecosystems in terms of efficiency of energy utilization, net energy production, and digestible energy production.* Total digestible nutrients (TDN), which are related to digestible energy, may offer the best available means of evaluating vegetation for grazing animals (Castle 1955). Some difficulty may be experienced in determining this unit due to inadequate coefficients of digestibility and nutrient requirements of specific animals at specific times.

4. *Consideration of antagonistic effects of various plant constituents on animal health.* Data on production and composition of vegetation, including nutrient production and composition, is of little value if some part of the complex is deleterious to animal health. For example, there is evidence that the "essential oils" of some plants may block digestion and even be harmful to rumen bacteria (Smith 1957).

SUMMARY

Potential, as related to a site or an ecosystem, is a vague term which must be qualified before it has much meaning. Evaluation of site or ecosystem potential must consider: (1) Expected uses of the described unit, (2) successional patterns with and without use and management by man, and (3) the time interval involved.

The plant community is a good measure of site or ecosystem potential. Its components indicate the ability of the total community to convert existing environmental factors into plant tissue as a result of evolution and preconditioning.

Production seems the best single dimension by which site or ecosystem potential may be evaluated. Production attributes which should be considered include: (1) Yearly production variations created by fluctuating weather cycles, (2) successional variations within ecosystems, (3) production of all species, (4) productive efficiency considering conversion of available energy to usable energy, and (5) energy and nutrient production for the consuming animal.

Floristic composition, an attribute dependent on the measurement method used, may serve to index conditions within and between sites. It cannot be used singly to evaluate the potential of these entities.

Research must: (1) Find ways to define and characterize ecosystems and ascertain the value of production and floristic composition in evaluating potential, (2) determine ecological and physiological responses of species and communities to establish successional potentials, (3) evaluate energy relations emphasizing usable energy production from energy available, and (4) consider production of antagonistic as well as beneficial plants and plant constituents.

MEASUREMENT AND EVALUATION OF SOIL MOISTURE AND TEMPERATURE AND MICROCLIMATE IN ECOLOGICAL STUDIES

John H. Ehrenreich

The importance of soil moisture and temperature and microclimate in site evaluation studies is well recognized. This paper discusses methods and principles used in measuring and evaluating these important site factors.

The water in the soil at a given moment can be ascertained by evaluating the entire water balance, which may be written as:

$$\pm \text{Soil moisture} = P - E - R - Q$$

where

P=total precipitation including rain, snow, condensation of water vapor, etc.
E=evaporation from the surface of soil and plants
R=runoff
Q=percolation

Because soil moisture is often difficult to measure in the field, it is frequently evaluated indirectly by means of topographic features, or soil profiles, or through factors that regulate water movement and retention. These factors will be discussed in another paper in this symposium.

The movement of water through the soil-plant-atmosphere system is in response to an overall *free* energy difference. *Free* energy gradients are determined by total pressure, temperature, concentration of water, and osmotic pressure. Water moves from regions of higher to lower potential energy as it moves through the soil into the plant root and through the plant to the leaves. The *potential* energy continuously decreases until the water reaches the leaves where evaporation is occurring. Here an amount of energy must be supplied through solar radiation and convection equal to the heat of vaporization (Gardner 1960; Perrier et al. 1961).

The flow of energy in an ecosystem or within a soil profile can be evaluated by considering the flow of energy to and from the system under study. The energy balance is a concept that relates all radiant energy arriving at the soil surface to that radiation reflected skyward, that used in evaporation of water, that reradiated to the atmosphere, or that stored in the system (Newman 1962). The energy balance may be stated as:

$$R = R_e + E + A + S$$

where

R=total radiant energy (insolation)
R_e=reflected radiation
E=latent heat (used in evaporation and condensation)
A=sensible heat (heats the air)
S=stored heat (stored in crop or soil).

Net solar radiation, which may be stated as $R_n = E + A + S$, is an expression of the incoming short- and long-wave radiation minus the reflected radiation (albedo) and the outgoing long-wave radiation. There are, of course, more insignificant factors influencing the expression of the net radiation formula. Tanner (1960) gives a complete enumeration of all of these factors and discusses their interactions.

The microenvironment of plants is a dynamic state caused primarily by changes, lags, and reversals in energy flux from day to night, day to day, and summer to winter. For latent heat these energy reversals may be represented as the amount of condensation (dew) and sublimations (frost) deposited on soil and crop surfaces at night and the amount of evaporation and evapotranspiration that occurs at these surfaces during the day. For sensible heat these reversals may be represented by daily maximum and minimum temperatures. The diurnal heat reversal under dry desert conditions results in the exchange of large quantities of sensible heat between the surface and the atmosphere above, whereas in humid climates much more of the energy is used in latent heat exchange.

The effects of temperature and soil moisture on yield are the results of a complex of interactions with other plant functions. At certain phenological stages temperatures may be more important than moisture, while at other stages of growth the reverse may be true. Some plant functions are most sensitive to soil moisture and temperature stresses than others (Haga et al. 1957). Moreover, reactions of plants to moisture and temperature stresses are not linear and vary greatly over the stress range. Thus, in range site evaluation studies it is not only important that environmental factors be properly measured, but that they be properly interpreted in light of the complex of soil-plant-atmosphere interactions.

SOIL-MOISTURE MEASUREMENTS

Soil-moisture changes are commonly estimated by (1) periodically sampling the natural soil profile by using gravimetric methods, tensiometers, electrical conductivity units, or nuclear moisture measuring devices; (2) measuring changes of soil moisture in confined soil samples; and (3) measuring consumptive use by vapor

flux through the lower atmosphere. Measurements by these methods will be discussed in detail.

Variations of these methods and other methods involving factors such as consistency, water-absorbing liquids, heat of solution, heat diffusion, calcium carbide, constant volume, and nitrogen offer little promise for range site evaluation research and are adequately covered in the literature (Lull and Reinhart 1955; Bloodworth and Page 1957; van der Marvel 1959; Burke and Krumbach 1959).

Gravimetric Method

The gravimetric method has been a standard technique for obtaining soil moisture. It is the only commonly used direct method of measuring soil moisture and has been indispensable for calibrating instruments used in indirect methods.

The gravimetric method consists of weighing a soil sample, ovendrying, reweighing, and expressing original moisture content in percentage of ovendry weight of soil. To convert gravimetric data to inches of water, as is commonly done, it is necessary to determine bulk-density values for the soil. Equipment is relatively inexpensive compared with that needed for other methods. It consists of tubes or augers, scales, moisture-tight cans, and drying ovens (Lull and Reinhart 1955).

Soil condition is very important in obtaining gravimetric samples. Free water in the soil may result in errors due to water loss when removing the soil sample. Where a wet soil layer overlies a dry one, such as with a perched water table, contamination of the drier sample may result. When the soil is dry and hard or has a high clay or sand content, there are problems in just getting the auger in and out or holding the contents in the sampler. In many forest and range soils, such as in the Ozarks, where stone content may range from 20 to 80 percent by volume, it is very difficult, if not impossible, to obtain adequate soil samples for moisture determinations using the gravimetric method.

Much time and labor are required for obtaining adequate soil-moisture data with the gravimetric method, particularly when it is necessary to derive a soil-drying curve to accurately depict rapid moisture changes. Moreover, such repeated sampling destroys the experimental area. For practical reasons, sampling is usually limited to a depth of 4 feet.

Evaluation of moisture differences is also hindered, for two samples cannot be taken from the same point. Thus, a moisture difference in successive samplings may be due to either an actual moisture change with time or to a variation in moisture content between sampling points. When moisture is expressed on a weight basis, the error may frequently be less than 1 percent. However, when it is expressed on a volume basis, the error is larger and more difficult to calculate since soil density and moisture are determined from different samples.

In spite of these disadvantages, the gravimetric method will probably continue to be used as a check against the indirect methods and in small or short-term studies in which the cost of using more elaborate equipment cannot be justified.

Tensiometers

Tensiometers are commonly used under field conditions of high moisture contents. They are essentially a porous ceramic cup connected to a vacuum gage or mercury manometer (Richards 1949). The system is filled with water, and, as the soil wets or dries, water flows into or out of the porous cup. This activates the pressure measuring device. The mercury manometer scale is recommended for research. It is accurate to 1 to 2 percent of the field-moisture range. Actually the tensiometer measures soil-moisture tension. To obtain soil-moisture content, it is necessary to relate moisture values from field or laboratory samples to tensiometer readings (Perrier and Evans 1961).

The instrument is available in single-cup and multiple units. The multiple unit may be valuable for establishing hydraulic gradients at a single location and can be used to trace wetting front movements.

Perhaps the main disadvantage of tensiometers for evaluation of soil moisture in range site work is that they measure moisture only in a tension range of 0 to 0.85 atmospheres. Thus, tensiometers would be best suited for use in humid areas, wet mountain meadows, or seeps.

Tensiometers are subject to errors from hysteresis effect in wetting and drying and also to high salt concentrations. Moreover, tensiometer readings are subject to daily variations due to temperature gradients between the porous cup and the surrounding soil (Haise and Kelley 1950). However, these variations can be minimized by taking daily readings when soil temeperatures are lowest.

This is one of the least laborious techniques for obtaining soil moisture once the tensiometer is calibrated and may be useful in range site studies to measure soil moisture from field capacity to saturation.

Electrical Resistance Units

The electrical resistance instruments are widely used for measuring soil moisture *in situ*. These instruments operate on the principle that the

conductivity between two electrodes embedded in a porous block and buried in the soil will depend on the moisture content of the soil (Olson and Hoover 1954; Lull and Reinhart 1955; Palpant and Lull 1953).

The three types of units commonly used are made of plaster of paris or gypsum block, fiberglass, and nylon. Proper installation of these units is extremely important. The soil must be moist enough to pack well. Unless the soil is repacked to at least its original density, a channel may develop through which water will travel to the unit. Proper repacking of the soil is particularly difficult when placing a unit below a hardpan or in very rocky soils. For practical reasons units are seldom used at depths of more than 4 feet.

Each soil-moisture unit must be carefully calibrated either in the laboratory or preferably in the field to establish the relation between the resistance of a particular unit and the soil-moisture content.

In field calibrations each stack of units requires an adjacent sampling area from which to obtain gravimetric samples. For point calibration these sample areas must be taken close to the units; however, they must not disturb the natural soil and moisture relations at the unit. This is difficult since 10 to 20 calibration points are needed to derive a calibration curve for each individual soil-moisture unit. To calibrate a plot, random samples may be taken over the area, and soil disturbance is less of a problem. An obstacle also occurs in soils of great variability since a difference of several percent in moisture content between duplicate calibration samples makes it difficult to determine whether the difference is due to measurement or represents soil conditions.

Electrical resistance units are subject to errors from hysteresis effect in wetting and drying, to temperature variations, and to high salt concentrations. The Fiberglas units have an advantage over other types of units because they contain a thermistor that gives soil temperature so that corrections can be made.

Durability of the soil-moisture units may also be a factor in longtime studies. Gypsum blocks have deteriorated in two growing seasons. Fiberglass units, however, have lasted as long as 7 years.

Once the units are properly installed and calibrated, readings can be easily and quickly made and converted to inches of soil moisture. The experimental error of various units may frequently be no greater than 1 percent; however, when expressing moisture on a volume basis, soil density must be obtained, and the same difficulties exist as with the gravimetric method. Because of the calibration difficulties, use of electrical resistance units may not be justifiable for studies of less than 4 years. These instruments do have an advantage over some other methods for measuring moisture in the shallow layers of surface soil. Electrical resistance units may have limited use in range site evaluation studies, if sources of error are considered and steps are taken to compensate for them.

Nuclear Method

The nuclear method of measuring soil moisture, while perhaps not yet as extensively used as some of the other methods, is considered by many to be the most reliable and promising one yet developed (Tanner 1960; Sartz and Curtis 1961; van Bavel et al. 1961; Stone et al. 1960). The neutron method is essentially a measurement of the number of hydrogen nuclei in the soil. Fast neutrons emitted from a radioactive source are slowed down or moderated by collisions with atoms of low atomic weight. Hydrogen is usually the only element of low atomic weight found in large amounts in the soil. A count of the moderated neutrons is thus essentially a direct measure of the moisture content of the soil. The occurrence of slow neutrons is largely independent of soil texture, structure, and aggregation (Merriam 1960).

Even though the manufacturers furnish calibration curves for each instrument, the units should be checked before using. The need for calibrating probes with a large body of soil requires much time and labor. Calibrations are made by installing access tubes for the probe, taking meter readings at specific depths, and taking gravimetric samples at the same depths around the access tube. Although such gravimetric sampling destroys the site, once the calibration curve is defined the instrument should be applicable to similar soils over a large area.

After the field calibration is made, verifying calibrations of probes can be much more easily done with NaCl, H_3BO_3, or other solutions (McGuinness et al. 1961; van Bavel et al. 1961). The probes should also be checked when there is a replacement of some of the electrical components or when major adjustments are made.

A 1- to 2-minute count is adequate for a single determination. Stone et al. (1960) reported that reproducability of data could be as refined as desired by merely taking enough counts to provide a sufficiently small random counting error. They reported that seven gravimetric sites are needed for each neutron site to give comparabe standard errors of the mean. Readings are converted directly to soil-moisture percent by volume so that determinations of bulk density are not necessary. The neutron method is not subject to ambiguities from moisture hysteresis effects, temperature variations, high salt concentrations, or

stoniness. Also, greater depths can be measured than by other methods.

Moisture measurements in the upper 12 inches of soil have been a problem because of neutrons escaping into the air, but now special probes are available specifically for surface-moisture readings.

In addition to moisture probes, both surface and subsurface density probes are available for obtaining *in situ* measurements of bulk density (Merriam 1960).

The neutron method has several disadvantages. A radiation hazard is possible unless recommended safety precautions are carefully followed. The original cost of the equipment is high compared with that for other methods. The first field calibration is very laborious and time-consuming. Although the equipment is portable, it is heavy. However, this problem can be overcome by mounting the equipment on handcarts. It is also very likely that manufacturers will soon design lighter equipment. Despite these disadvantages, the neutron method is the most promising one for use in determining changes in soil moisture for range site studies.

Prediction Techniques

A prediction method of estimating changes in soil moisture in the surface foot of soil has been developed by Carlson et al. (1956) and Campbell and Rich (1961). It is essentially a bookkeeping system that requires a record of (a) daily rainfall, (b) field-maximum-moisture content, (c) field-minimum-moisture content, (d) minimum storm (the smallest storm that contributes to soil moisture), (e) soil-moisture-accretion regressions for class I accretion (when total rainfall is less than available storage) and class II accretion (when total rainfall equals or exceeds available storage), (f) seasonal-soil-moisture-depletion curves, and (g) transition dates on which depletion rates change.

Although this method was developed for application only to the surface foot of soil and to areas where rainfall is the principal source of precipitation, it shows promise for being extended to other forms of precipitation and to the full root zone. Campbell and Rich (1961) reported that soil-moisture estimates from this method offer improvement over rainfall measurements in correlations with grass growth, both within and between years.

The prediction method of estimating soil moisture holds promise of being useful in future range site evaluation studies where only general knowledge is available and where it is impractical, due to lack of time, funds, and equipment, to obtain more intensive soil-moisture information.

Lysimeter Method

Lysimeter methods are used not only to determine changes in soil moisture for specific plant covers but also to depict the entire water balance, including evapotranspiration, precipitation, percolation, surface runoff, and changes in soil moisture.

Changes in soil moisture can be weighed very accurately with some lysimeters. McGuinness et al. (1961) reported that weight changes are recorded to the nearest 5 pounds in Coshocton weighing lysimeters—a change equivalent to 0.01 inch of water over the surface of the lysimeter. However, as van Bavel (1961) pointed out, lysimeters can also yield erroneous values unless their construction and operation meet certain requirements. To yield reliable data, lysimetric samples must be representative of the exposure, moisture content and tension, thermal conditions, soil structure, and root development of the vegetation type being studied. However, lysimeters rarely can meet all of these requirements; thus, care must be taken in applying lysimetric data to large areas in natural conditions. A main disadvantage of using lysimeters in range site evaluation is the cost, time, and labor involved in such installations.

Despite these drawbacks, lysimeter studies are valuable in range site evaluation research because there is no other way to obtain such complete information on basic soil-plant-water relations.

Estimating Consumptive Use of Soil Moisture by Micrometeorological Methods

The measurement of consumptive use of soil moisture (evapotranspiration) by meteorological methods has been given much attention lately. Evapotranspiration can be estimated by measuring energy disposition at the earth's surface or by aerodynamic (wind profile) methods which measure the flux of water vapor.

The energy balance of a crop volume is, as given earlier, $R_n = E + A + S$. Evapotranspiration can be evaluated by measuring the various factors of this formula. Although this formula does not account for energy stored in the vegetation or energy used in photosynthesis, it is adequate for measuring consumptive use of soil moisture. The net radiation and soil heat fluxes can be measured directly with suitable instruments available commercially. The sensible and latent heat terms can be separated by using the Bowen ratio, which requires the time-averaged measurement of the vertical temperature and vapor pressure gradients (Tanner 1960).

Under adiabatic conditions sensbile heat and latent heat fluxes may be found from the vertical

gradient of the horizontal wind (wind profile), the temperature gradient, and the vapor pressure gradient, assuming equalization of the eddy coefficients. It is usually more difficult to measure and interpret these data than the Bowen ratio energy balance data (Tanner 1960).

Penman (1948) developed a method of using the energy balance approach for estimating evapotranspiration. This method treats evaporation from soils and crops as a physical process and requires knowledge of four meteorological parameters: (a) Duration of bright sunshine or net solar radiation, (b) air temperature, (c) air humidity, and (d) windspeed. Penman assumes that evaporation from a plant cover and water are proportional; however, this is frequently not the case (Gerber and Decker 1960). He further suggests that the heat exchange to and from the soil could be neglected. However, Gerber and Decker (1960) found that the inclusion of this component in the heat budget improved the estimate of evapotranspiration, and they modified Penman's equation to include this factor.

Gerber and Decker (1960) found that the Penman method gives reliable estimates of evapotranspiration when the surface soil is wet. However, the method usually overestimates evapotranspiration when the soil surface is dry, even though there may be abundant subsurface moisture. This is because the amount of sensible heat transferred to the atmosphere is underestimated.

The Thornthwaite (1948) method of measuring potential evapotranspiration from meteorological data has been used extensively. His formula assumes that evaporation can be estimated if sensible heat exchange between air and the crop is small. Pelton et al. (1960) pointed out that the Thornthwaite method may give good agreement with the Penman method when applied on a long-term basis but that it is unsuitable for short-time intervals.

Mean-temperature methods may be useful for measuring evapotranspiration in range site evaluation studies in humid regions where annual estimates of either the growing season or evaporation are desired. However, more recent techniques and instrumentations, as described by Tanner (1960) and Gerber and Decker (1960), appear to have greater usefulness in range site research. These later micrometeorological methods of estimating consumptive use of soil moisture have the advantage of permitting estimates to be made for periods of 1 hour or less. They also appear promising for estimating daily evapotranspiration with effort comparable to that required for weekly sampling by soil-moisture methods. There are, however, many instrumental and theoretical difficulties to overcome, and the amount of reliable data is small.

SOIL TEMPERATURE MEASUREMENTS

There are several measurement systems and instruments described in the literature which will efficiently yield accurate information on soil temperature for range site evaluation purposes; e.g., thermistors, resistance thermometers, thermocouples, bimetal dial thermometers, and mercury-in-glass thermometers (Fulker 1958).

Thermistors and resistance thermometers are particularly well suited for measuring soil temperature in range site evaluation studies. Tanner (1958) described an *in situ* method of using resistance thermometers that gives the mean soil temperature or spacial average in a single temperature reading from several locations at the same soil depth or over a depth range. This is done by connecting the thermometers in series to a resistance-measuring bridge. The temperatures can be recorded automatically with a strip-chart potentiometer.

Thermocouples can also be used to obtain a spacial average of soil temperature from a single reading or a series of readings. Burrows (1959) described a method whereby thermocouples connected in parallel may be used to obtain a spacial average of soil temperature in a single reading. However, the necessity of an ice bath for the cold part of the system makes the use of thermocouples difficult in field studies.

Measurements of soil temperature with thermistors, resistance thermometers, and thermocouples are greatly facilitated by the use of automatic recording potentiometers. Larson et al. (1959) described a multipoint recording potentiometer using copper-constantan thermocouples in combination with a switching device capable of recording up to 320 separate temperatures in one cycle. Of course, it must be remembered that the readings recorded with a potentiometer are only as accurate as the potentiometer itself.

Larson et al. (1959) described a bimetal dial thermometer that had three indicators. One indicated the current temperature, a second the maximum temperature, and a third the minimum temperature. They found that these instruments were easy to read and could withstand normal field exposure. These bimetal dial thermometers would be well suited for obtaining soil temperature readings in range site studies.

Mercury-in-glass thermometers have been widely used for obtaining soil temperature data. They are relatively accurate at depths below 1 inch; however, they are very time-consuming when used for many readings. These thermometers would probably only have limited use in range site evaluation studies.

The choice of instrument will depend greatly on the type and accuracy of information desired. Complete diurnal temperature descriptions, the

average daily soil temperature, and daily maximum and minimum temperatures provide data to calculate degree-day and other plant indices. With some instruments these data can be obtained directly; with others it may be necessary to obtain temperature variations by reading at certain times during the day. Bimetal dial and mercury-in-glass thermometers are accurate to less than 1° F., while other instruments mentioned are capable of much more accurate measurements.

Most of the instruments mentioned here will have some value for obtaining soil temperature data in range site evaluation studies; however, the thermistors or resistance thermometers used in conjunction with an automatic recording potentiometer probably would be most suitable.

MICROCLIMATIC MEASUREMENTS

Considerable interest is being taken in the effect of microclimatic factors on plant growth. Net radiation can be measured directly with net radiometers, which essentially measure shortwave incoming radiation and incoming longwave sky radiation on one element and reflected soil radiation (albedo) and outgoing long-wave radiation on another element (Tanner 1960). These instruments are usually operated near the ground and about 1 meter above the plant cover to obtain measurements of vertical distribution of energy.

The ventilated net radiometer described by Suomi et al. (1954) is one of the most accurate. The main advantage of this model is that the ventilation of the flux plate may be balanced so that the heat losses from the upper and lower surfaces are equalized. Recently a simpler, relatively inexpensive net radiometer was developed by Suomi and Kuhn (1958). This instrument has a larger error than the ventilated radiometer, particularly at low sun angles, and must be shielded from rain and dew (Tanner 1960). However, since it can be used where power is not available, it is advantageous for many field studies. Fritschen and Van Wijk (1959) reported satisfactory results from the use of several thermal transducers as net radiometers. The radiometers were connected to either multiple- or single-point Brown strip-chart potentiometers.

Instruments and methods for measuring soil temperature in the microclimate are described in the previous section. Tanner (1960) also describes a method of measuring soil heat flux depth with flux plates (2 by 2 cm.) connected in series and located at different sites to provide spacial sampling. The heat flux in the soil layer between the surface and the flux plate depth can be measured by calorimetry.

Many different types of instruments and mounts that give accurate measurements of air temperature and precipitation, humidity, and wind are available from commercial scientific instrument laboratories. Tanner (1960) describes a method of obtaining measurements of air temperature with instruments mounted on a boom which travels in a horizontal 15-meter arc over the surface. He measured the temperature difference over a 60-cm. vertical interval with a 5-junction thermopile in aspirated nozzles which provide radiation shields. Dewcels, as described by Tanner and Suomi (1956), can also be mounted on movable booms to obtain spacial measurements. Wind profile can be measured directly with anemometers positioned at various elevations to measure wind gradients.

Light can be measured satisfactorily by use of the Integrating Light Meter described by Logan (1955). Atkins (1957) and Minckler (1961), using Norwood Director light and Brockway exposure meters, respectively, both found that incident light meter readings were closely correlated with results obtained with the more expensive Integrating Light Meter.

Although there are many types of instruments available that give accurate measurements of microclimatic factors, there are many theoretical difficulties to overcome in relating such data to vegetative responses. There is a definite need for more methodology research to assess the role and importance of microclimatic factors in range site evaluation studies.

SUMMARY AND CONCLUSIONS

Soil moisture and temperature and microclimatic factors should be considered in range site evaluation studies. The use of the total water and energy balance concepts should be very useful in interpretation and application of data obtained.

All of the methods for measuring changes in soil moisture, except for the lysimeter method, have only a certain range over which the instruments are uniformly sensitive. Also, the lysimeter method cannot depict moisture changes by horizon or layers except when used with other instruments. Tensiometers are most accurate from field capacity to saturation, but they are of little value for measuring low-moisture contents. Electrical-resistance units and nuclear instruments are most accurate for measuring moisture contents from below wilting point to field capacity.

Stone in the soil affects accuracy in soil-moisture measurements with the gravimetric method and a calibrations with the tensiometer, resist-

ance, and nuclear methods. However, the nuclear method is least affected since only one field calibration may be necessary. Accuracy of soil-moisture records is also affected by the need for separate soil-density measurements with all except the nuclear method.

Each of the methods for measuring soil-moisture changes has advantages and disadvantages. Though the gravimetric method is very laborious and subject to several errors, it is useful as a check against the indirect methods and in short-term studies requiring few measurements. The indirect methods have an advantage over the gravimetric method in that they provide continuity of soil-moisture records in both time and space.

Of the indirect methods the tensiometer and resistance methods are least useful for range site evaluation studies since they require elaborate calibrations of each soil-moisture unit and are subject to serious errors of hysteresis effect, temperature variations, and high salt concentrations. However, the transiometer method is still best for measuring soil moisture in the range from field capacity to saturation. The lysimetric methods have a use in developing basic plant-water relations, but they are not practical for extensive use.

The prediction technique is very promising, but it is still in the development and testing stage. Meteorological methods for obtaining evapotranspiration definitely have a place in site evaluation research. The nuclear method will probably be the most useful for measuring soil moisture in such studies, and it is not subject to all of the errors of other methods. When measurements with neutron probes are independent of field calibrations, they give the only true *in situ* measurements.

Evaluation of soil temperatures and microclimatic factors, such as net radiation, air temperature, wind, and light, is not hampered as much by lack of instruments capable of measuring these factors accurately enough for site evaluation purposes as it is by the lack of data, and related interpretation, on the use of these instruments in such studies.

Selection of instruments will depend not only on their relative merits, as pointed out here, but on equipment and facilities already on hand, finances, and experience of personnel.

COMMITTEE REPORT ON RANGE SITE MEASUREMENT AND EVALUATION

Lack of reliable means of estimating the productive potentials of wild lands is a major obstacle to efficient management of range and wildlife habitat. This impediment is especially acute where vegetation and soils have been markedly altered by past use. Managers of public lands particularly need reliable scientific criteria for estimating land capabilities in order to satisfy demands for increasingly intensive management. Correction of such a basic deficiency warrants priority in our research programs.

Capabilities, or potentials, of primary concern here relate to production of vegetation desirable for livestock and wildlife use and soil improvement or protection. Reliable estimates of potentials for such attributes as herbage production and species composition of natural or introduced communities are necessary to set management goals and to determine condition of range used by livestock or game. Such potentials, along with similar ones for alternative uses and values such as timber and water, eventually will guide decisions regarding kinds of wild-land usage as well as management practices.

Extreme variations in vegetation, topography, soils, and climate, and corresponding variations in productive potentials, are characteristic of the wild lands with which we are concerned. Consequently, determination of potentials is complex. For convenience or simplicity, it is customary to consider a complex landscape as being made up of a mosaic of units—each being relatively homogeneous in regard to environmental factors and productive potential. Such units here are termed "sites." Identification and classification may emphasize any feature of the landscape and can be as general or detailed as appropriate for the point of interest. Commonly the term "site" is applied to the combination of physical and biotic factors of an area supporting a particular plant community. But to some ecologists the plant community is part of the site. In this sense, site is approximately synonymous with "ecosystem."

The present discussion deals primarily with physical factors of the site—topographic, climatic, and soil properties—in relation to potential. Our current principal interest in the plant community concerns the degree to which it expresses or reflects site potentials, although for some purposes and situations the community itself may be of primary interest.

Very little has been done to quantitatively evaluate range sites. There are many reasons for this, including the difficulty in evaluating simultaneously a number of highly variable and interrelated environmental factors. However, with the recent development of electronic computers we have gained new freedom in applying

efficient multivariate analysis techniques which offer hope for effective study and rapid progress.

Background from foresters' experience.—We can profit from the experience of foresters who have been studying site quality from the viewpoint of timber production for several decades. Their progress has been facilitated by finding that a site index based only on tree height growth at a given age (50 or 100 years) provides a useful expression of productive capacity for timber. They have used mathematical models in developing prediction equations of the general form, $Y=f(X_1, X_2, \ldots X_n)$, for relating productive capacity to various site factors as the independent variables.

Understory vegetation is useful for estimating potentials of forest sites in northern Europe and in Canada. There the presence or absence of a few indicator species or simple communities of low vegetation correlates with site quality for important species of northern trees. Recent results suggest similar possibilities for ponderosa pine in northern Idaho and eastern Washington. However, the plant indicator approach has been less successful in southern Europe and elsewhere in the United States. Here species appear to have wider ecological amplitude, and communities seem more complex. This has forced consideration of a sizable number of species in predicting site quality for trees. But, recent results indicate that further study of indicator vegetation is warranted, especially in combination with other environmental factors in a "total site" concept.

Soil properties and site factors most commonly found related to forest site index in American studies are: Depth of "A" horizon, total "effective" depth, texture (particularly silt and clay), aspect (exposure), slope steepness, and position on slope. Although these can be interpreted as supporting the philosophy that available moisture is the key to forest site productivity—with aeration and rooting space going hand in hand with moisture availability—the same factors also are related to the supply of available nutrients. Parent material and levels of nitrogen and mineral elements have been found to be related to site quality under some circumstances. Because of its influence on soil properties, parent material is a useful criterion for stratifying sites in the initial phases of study. Soil survey data serve the same purpose.

Soil survey data are becoming more useful for predicting site quality as soil classification is modified and refined. Although past efforts to correlate site index of trees with soil series, types, and phases often have been disappointing, the combination of refinements in soil survey and intensification of site research offers considerable promise for improving classification of forest soils.

Existing vegetation as a measure of range site potentials.—At present, very little can be quantitatively interpreted or predicted from existing vegetation regarding potentials for different kinds or amounts of production. Not enough research has been directed at this problem to determine which attributes of plant communities are most useful for prediction or to determine the accuracy obtainable. So-called "climax" communities are generally assumed to reflect specific sites. But they have not yet been adequately evaluated and interpreted in terms of potentials for production of forage, nutrients, energy, or alternative products. If this were done, climax communities should have great predictive value. The same can be said of developmental or seral communities. "Climax" may not be essential to range site evaluation. Although it is a useful concept and point of reference, examples of it are rare, and its implications sometimes are misleading. For example, succession is assumed by some to progress toward maximum utilization of the environment, which seems to imply maximum productivity in climax situations. Actually, greater production under subclimax or seral or disturbed conditions has been found repeatedly.

The total plant community probably offers the best available expression of a site, and all components should be measured. The community also must be ordinated in the successional pattern or referenced to other communities in order to complete the picture of site potentials.

Although the choice of vegetation measurements presents problems because of varied interests or viewpoints, productivity in terms of weight appears most meaningful and useful. It provides an effective approach to ecological significance as well as to forage production and related attributes, and lends itself to interpretation from a broad spectrum of interests and with successive refinements. For example, productivity could also be expressed in terms of energy, digestible nutrients, or animal production if appropriate conversion factors were available or were obtained from supplemental study. Collection of weight data admittedly presents serious problems related to different growth periods for the various species and to weather fluctuations. But such data seem to provide the best index of productivity for use as the dependent variable in developing prediction equations.

Floristic composition, by itself, presently has only limited value in site evaluation because quantitative interpretation generally is not feasible with information now available. However, composition—and possibly mere occurrence of indicator species—should have predictive value when enough information is accumulated. It needs investigation both as a dependent and as an independent variable. Combined composition and

production data are most informative and will enhance progress in studies of range site evaluation.

Site factors and soil properties.—Promising attributes for use in evaluating range sites can be rationalized from related experience in forestry and consideration of factors influencing plant growth. Following the foresters' lead, we anticipate a mathematical approach by which production or growth potential, as the dependent variable, is related to site attributes as independent variables in developing prediction equations. Although environmental factors directly involved in plant growth—oxygen, carbon dioxide, water, mineral nutrients, and radiant energy—might be expected to be the most useful criteria for site evaluation, they are not. Some of these are so seldom limiting or else are so uniform over large areas that they have little predictive value. Direct growth factors associated with the soil apparently vary among sites, but they are not readily measured in the field. Consequently, the indirect approach has been widely adopted. However, site factors and soil properties most closely related to growth factors generally have been the most satisfactory criteria.

Site factors that have been most useful are topography (aspect, gradient, and position on slope) and parent material. Aspect markedly influences solar radiation and temperature, and hence moisture and soil properties related to productive potentials. For regression analysis it commonly is measured in degrees azimuth. Shape or curvature of slope and position on slope can be expected to be predictive because they influence moisture relations. Slope gradient has not been very useful when related properties such as runoff, erosion, and soil depth also are evaluated. Parent material influences physical and chemical properties of soil and should be predictive even though it has often not proved useful in the past. Using parent materials as discrete variables has been one difficulty. They are actually continuous variables and ought to be treated as such, but quantification is an obstacle at present.

As already mentioned, physical soil properties found most effective are depth and texture. These usually are sampled by horizons, although depth classes sometimes are appropriate, for example, in undifferentiated soils. They directly influence moisture, which often is most effectively expressed on a volume basis. This expression requires bulk density measurement, which also might have predictive value because of its relation to permeability, drainage, and aeration. Other measures for expressing these latter characteristics include depth to mottling, silt and clay content or imbibitional water value of subsoil, and pore space.

Chemical characteristics of the soil that appear most promising as criteria in site evaluation include nitrogen content, organic carbon (organic matter), phosphorus, sulfur, and exchange capacity. On arid ranges where soluble salts reach detrimental amounts, measurements of electrical conductivity and exchangeable sodium should be pertinent.

As already mentioned, chemical criteria have not proved as useful as others in studies of forest sites. This is likely attributable to the difficulty of measuring the nutrient-supplying capacity of soils. Common laboratory methods of measuring "exchangeable" and "available" nutrients are not entirely adequate, even for agricultural crops. Biological tests utilizing pot cultures of standard crop plants are promising, although they are costly in greenhouse space and time requirements. Reduction of costs through substitution of fungi or algae as the test plants offers promise. Foliar or plant tissue analysis, in common use in agriculture and horticulture, merits investigation for assessing nutrient levels in range sites.

Moisture, temperature, and microclimate.—Measurement of these factors warrants special consideration because of their dominating ecological influence and their importance to range study. Their influence may be considered from viewpoints or interests ranging from tolerances of individual plants to the water and energy budgets of ecosystems.

The water balance at a given time may be expressed as:

Soil Moisture = Precipitation − Runoff − Percolation − Evapotranspiration.

The energy balance in relation to net solar radiation, R_n, (total incoming radiation minus reflected radiation and outgoing long-wave radiation) can be stated as:

R_n = Latent heat + Sensible heat + Stored heat.

The energy budget is highly dynamic, with hourly, daily, and seasonal changes in energy flux, and a complete reversal of direction between day and night. For latent heat the energy reversals are represented by the amount of condensation on soil and plant surfaces at night and of evapotranspiration during the day. Thus, evapotranspiration is one of the most important items in both the water and the heat budgets pertaining to range ecology and site evaluation.

Evapotranspiration, or soil moisture use, commonly is estimated from (1) changes in soil moisture found by periodic sampling of the natural soil profile, (2) changes in confined soil samples (lysimeters), or (3) from measurements of consumptive flux through the lower atmosphere.

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Soil moisture measurement by the gravimetric method has been the standard technique for direct measurement and for calibrating instruments used in indirect methods. It is still best for one-time sampling or very short-term studies. In repeated sampling for measuring changes in moisture, other methods are usually more efficient: The nuclear method (neutron probe), tensiometers (porous cup-monometer system), and electrical resistance units (gypsum block, Fiberglas, or nylon units). The nuclear method is most versatile and generally most efficient—especially where stoniness or salt concentration is a problem. Tensiometers are good for use in wet soils or moisture contents above field capacity. Resistance units are effective at low moisture levels and are rapid to read, but they require more time for installation, calibration, and computation.

Evapotranspiration measurement with lysimeters is not practical on an extensive scale but provides the most precise and complete data on soil-plant-water relations.

Estimation of moisture use by meteorological techniques is receiving much attention and warrants consideration in ecological research and site evaluation. Formulae (e.g., Penman's and modifications) based on the energy balance equation given above have been shown to be reasonably reliable. Recent improvements in techniques and instrumentations promise greater efficiency than soil moisture sampling methods for estimating evapotranspiration.

Recommended research.—We conclude that our major obstacle in range site evaluation is lack of experience. There seem to be no unsurmountable problems in measurement of pertinent site factors. We mainly need to direct research toward the identification and evaluation of the factors and measurements most closely related to productivity, and toward the development of appropriate prediction formulae. Concerted effort in comprehensive studies employing multivariate analyses is recommended.

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Measurement and Evaluation of Range Use by Livestock and Game

METHODS FOR MEASURING FORAGE UTILIZATION AND DIFFERENTIATING USE BY DIFFERENT CLASSES OF ANIMALS

Dwight R. Smith, Pat O. Currie, Joseph V. Basile, and Neil C. Frischknecht

The object of measuring forage utilization may be as simple as to ascertain when a single plant species has been grazed to a desired height; or it may be as complex as determining the effect on plants of removing various reproductive organs or photosynthetic tissue at specific growth stages.

Percentage of herbage removed is the most common expression of utilization today. But whether percentage removal is the best concept of utilization can be questioned. Associated with the development of "utilization" methods have been repeated attempts to draw attention to the concept of how much herbage must not be grazed.

For many years, the need to leave some seedstalks ungrazed has been recognized (Jardine and Forsling 1922). In 1939, Clark suggested that we "should be concerned more with how much herbage need be left to insure the life and productivity of a plant than with how much forage can be removed." Sampson (1952) raised the question: "How closely may a range be grazed without damage to forage stand and soil?" This concept of amount or "residue" remaining was applied, and standards were determined, on California annual ranges (Hormay and Fausett 1942; Bentley and Talbot 1951). More recently, Bement and Klipple (1959) used the same principle on the short-grass plains in Colorado.

Hyder[1] commented that, when emphasis is placed on percentage removal, primary attention is directed to methodology in itself, but when emphasis is placed on herbage remaining, attention is drawn to the ultimate objective, proper use standards. However, utilization expressed as a percentage removal is important in evaluating animal preferences under specific conditions of species, composition, yield, distribution, availability, and season of grazing.

Another concept emphasizes systems of grazing and minimizes importance of degree of grazing by permitting "full" use of plants at certain periods. This approach to range utilization was presented by Hormay and Talbot (1961), who described a rest-rotation grazing system for perennial bunchgrass ranges. Such a concept virtually eliminates the need for determining levels of grazing because other objectives of plant and animal management are overriding; any harmful effects of grazing are supposedly overcome by allowing plants to regain vigor and reproduce during rest periods.

The purpose of this paper, however, is not to reconcile concepts but to describe and evaluate present methods and recommend possible new approaches to estimating utilization. Whether or not the final expression is percentage removal, residue remaining, or condition and trend is a matter of mathematics and interpretation.

PROBLEMS OF INTERPRETING UTILIZATION

Some methods of utilization measurement require a knowledge of forage production, both in implementing the technique and interpreting and applying the results. This poses some vexing problems. Should the "production" value needed in the utilization equation be: (1) Herbage production on ungrazed areas measured at the peak of the growing season, (2) ungrazed herbage measured at the end of the grazing season, or (3) total cumulative growth on a grazed range?

Translocation of nutrients, weathering, and other "disappearance" factors progressively, but not always uniformly, reduce weight of herbage

[1] Hyder, D. N. What's wrong in forage utilization methodology. 1958. 18 pp. (Unpublished manuscript.)

after the peak growth period. Lovell (1961)[2] found that grasses on the sandhills and sandy plains of eastern Colorado reached maximum air-dry weight between late June and mid-July. Weight loss varied greatly by species. Total grass production dropped about 15 percent by September 7 and another 33 percent by March 18. Turner and Klipple (1952) reported reductions of more than 30 percent of the maximum herbage weight of blue grama during the summer and fall. Additional losses occurred during the winter.

The effects of time and manner of grazing on herbage production must also be considered. Stoddart and Smith (1955) state: "Although a single harvesting at the end of the growing season usually produces the greatest yield possible under dry-range conditions, there are exceptions to this." Periodic herbage removal from some plants in summer-rainfall areas may increase total yields (Lang and Barnes 1942; Turner and Klipple 1952). Total production of cool-season grasses under drier growing conditions, however, may be reduced markedly by grazing during the growing season (Cook and Stoddart 1953). The response of shrubs to browsing varies tremendously with species, time and level of use, and climate (Sampson and Malmsten 1926; Garrison 1953).

The amount of photosynthetic tissue and reproductive parts that remain after grazing greatly influences production of individual plants. Branson (1953) illustrates the importance of the height of growing points and the ratio of fertile to vegetative stems in determining a plant's resistance to grazing. Brown (1954) maintains that determining an appropriate utilization level is fundamentally a physiological problem involving consideration of the plant's opportunity to fulfill the functions of root growth, carbohydrate storage, and reproduction.

These problems illustrate the need for utilization measurements that can be readily interpreted. While it is recognized that no one utilization method satisfactorily resolves all problems, the following discussion of existing methods stresses strong and weak points and suggests applications to specific situations.

METHODS FOR DETERMINING UTILIZATION

Utilization has been measured by a variety of methods. These may be classed as follows: (1) Methods based on differences before and after grazing or between grazed and ungrazed plots or plants; (2) methods based on measurement, correlation, and regression of factors related to utilization; and (3) methods based on general observations and comparisons with predetermined standards of utilization.

Methods Based on Differences Before and After Grazing or Between Grazed and Ungrazed Plots or Plants

Actual Weight

Clipping and weighing herbage immediately before and after grazing, or on grazed and adjacent ungrazed areas, is a simple and direct way of measuring forage utilization. This approach is generally known as the actual weight (or difference) method. It was used by Beruldsen and Morgan (1934), who clipped and weighed herbage samples located at random before grazing and 1 day later, after grazing. For longer grazing, a system of paired caged and grazed plots is frequently used. If plots are closely paired, precision may be increased materially (Klingman et al. 1943). If plots are not paired, however, loss in precision may result. Where vegetation patterns are especially heterogeneous, efficiency may be increased by using single plots located at random. Where grazing is uneven, clipping of two or more grazed plots for every caged one may be advisable. There are differences among men in clipping of plots, but bias can be avoided by working all men in each pasture or having each man handle a replicate. Klingman et al. (1943) found, too, that it is more efficient to place cages singly rather than in groups.

A desirable feature of the actual weight method is its simplicity and directness in determining utilization. Little training is required. Accuracy in measuring herbage on a plot is generally high. Height and manner of harvesting samples, however, can introduce an inherent bias in the calculation of utilization. Sampling errors may be high if the time required for clipping forces acceptance of inadequate plots to sample the range. The method is particularly valuable for research on small pastures where grazing periods are short, utilization is relatively uniform, and regrowth is not important. Where grazing periods are long and cages are used, differences in growth on protected and grazed areas may distort the production base used in determining utilization. Also, favorable growing conditions under cages with less than 2-inch mesh have been reported to result in higher yields than those for uncaged plots (Cowlishaw 1951; Heady 1957). The principal disadvantage of the

[2] Lovell, Gilbert R. Trend of forage and nutrient production of grasses on sandhill and sandy plains sites in northeastern Colorado. 1961. (Unpublished master's thesis on file at College of Forestry, Colo. State Univ., Ft. Collins.)

method, and the one that often precludes its use in range experiments, is the cost. This is due to the great number of plots required to sample utilization in ranges where utilization, species, and production vary greatly due to topography, vegetation, soils, or other site differences.

Movable Cage

Recognizing that herbage production may be affected by grazing during the growing season, a Joint Committee of the American Dairy Science Association and American Society of Animal Production (1943) suggested modification of the actual weight method through the use of paired plots, moved every 2 weeks. In this modification, herbage is clipped from temporarily caged and grazed plots at the end of each 2-week period. The difference represents the amount of forage consumed by animals during that period. By including regrowth, this method may provide a better measure of forage production and utilization than that furnished by continuously caged plots.

The movable cage method requires much work in clipping plots and handling cages. Nevertheless, the method is well adapted for intensive research where grazing seasons are relatively long and knowledge of cumulative production of grazed plants is needed.

Weight Before and After Grazing

Another modification of the actual weight method was used by Cassady (1941) on summer sheep range. This method entailed clipping and weighing a predetermined number of plant units of key forage species immediately before and after a short period of grazing. The plant unit can be a twig, leaf, or whole plant. A predetermined number of plant units, usually 10 to 20, constitutes an observation (the number may vary from 1 to 100 depending upon size and heterogeneity of plant units). Cook et al. (1948) further amplified the method in studying the nutritive content of forage utilized by sheep.

In a recent study of jackrabbit food habits on the desert shrub type in Utah (Currie 1963),[3] the before and after method was 90 percent as efficient as the actual weight method for a given sampling intensity. Time required for clipping designated twigs, however, was much less than that required for clipping the paired plots.

Because of its rapidity, simplicity, and procedural soundness, the before-and-after method has numerous advantages if limited to areas where grazing is completed in a short time or to times when there is no regrowth.

Twig Length Before and After Browsing

This system of evaluating browse utilization was initiated in Utah in 1925 (Nelson 1930). Since then it has received widespread use and adaptation (Aldous 1945; Dasmann 1951; Varner et al. 1954). It is similar to the before-and-after method except it is based on twig lengths rather than weight. The method gives quantitative results, yet it is simple and fairly rapid to use. When a growth index is established each season, twig measurements before and after browsing offer a practical means for detecting year-to-year trends in utilization.

If seasonal growth is recognizable, twig lengths can be measured accurately. However, twig measurements are not precise indicators of percentage use. Twig length is not directly proportional to weight, and the discrepancy is greatest in species with the most sharply tapered twigs. Yet if proper use, expressed as percentage of annual growth removed, is known for a species, and if length-weight relationships of twigs remain relatively constant from year to year, this objection is not serious.

As for all methods of determining shrub utilization, criteria for defining availability are important. Results will be biased if measured twigs are unavailable because of physical barriers or other reasons.

Reduction in Height

In this method, difference in average height of leaves on grazed and ungrazed areas is used to calculate percentage utilization. Pechanec and Pickford (1937a) pointed out, however, that it is erroneous to assume that weight of grasses is reduced proportionately as height is reduced by grazing.

Ocular Estimates

The need for more intensive sampling of range units in the time available has encouraged development of methods in which forage utilization is determined by ocular estimation instead of actual measurement. The *Ocular-Estimate-by-Plot Method* was first used in 1933, according to Pechanec and Pickford (1937a). These authors also discussed a modification called the *Ocular-Estimate-by-Average-of-Plants Method*. By the former method, utilization of individual species is estimated on a plot basis. By the latter method, utilization of each plant within the plot is estimated separately and individual estimates are averaged.

[3] Currie, Pat O. Food habits of the blacktailed jackrabbit (*Lepus californicus*) and forage competition between jackrabbits and domestic livestock on native range in northwestern Utah. 1963. (Unpublished Ph.D. dissertation on file at Utah State Univ., Logan.)

An ocular estimate method for browse ranges is the *Estimate-of-Twig-Utilization Method.* It is similar to the ocular-estimate-by-plot method except that twig length rather than weight is estimated. Seasonal growth of certain shrubs such as sagebrush (*Artemisia* spp.) or snowbrush (*Ceanothus velutinus*) is difficult to estimate. For such species, comparisons of browsed and unbrowsed plants may be needed to facilitate ocular estimation. These steps may be followed (National Research Council 1962): (1) Examine shrub to determine extent of cropping, (2) mentally reconstruct shrub as it would appear had it not been cropped, and (3) estimate percentage of twig length utilized.

On shrubs such as bitterbrush (*Purshia tridentata*), annual twig growth is easily recognized. For this species, Hormay (1943) proposed the following procedure for determining utilization: (1) A production index is calculated by multiplying crown area by estimated ungrazed twig lengths for each plant, (2) an index of total production on a plot is the sum of these products for all bushes in the plot, (3) a utilization index for each plant is obtained by multiplying the production index by the estimated percentage utilization of the twigs, (4) an index of total twig utilization is the sum of all these products for all bushes on the plot, and (5) the average percentage utilization is calculated by the formula:

$$\frac{\text{Index of total twig utilization}}{\text{Index of total twig production}} \times 100$$

Aldous (1944) reported an ocular estimate method used for a variety of shrubs and trees. A 1/100-acre circular plot is recommended in which twig utilization is estimated by species and recorded by broad percentage classes.

Passmore and Hepburn (1955) used a different approach for estimating use on browse ranges. They estimated percentage of the twigs utilized on plants within long, narrow plots. Effects of browsing were further evaluated by counting stems killed and stems mutilated by past browsing.

A variation of ocular estimate methods recommended by the National Research Council (1962) is one in which average uncropped leader length, average cropped leader length, and percentage of leaders cropped are estimated. Average percentage utilization is obtained by calculating percentage of leader length browsed and multiplying this amount by the percentage of leaders that have been cropped.

Ocular estimate methods generally permit much more intensive sampling per unit time than do methods that require measuring or clipping and weighing. While this may result in lower sampling errors, personal errors on a given plot may be higher when ocular estimate methods are used. A related example was given by Smith (1944), who compared density estimates made by an eight-man crew. After 7 days of training, the estimators still made significantly different estimates. Also, an individual, estimating the same plot, had significant inter- and intra-daily variations. On the other hand, Reid and Pickford (1941) found the ocular-estimate-by-plot method and a measurement method, the stubble-height (height-weight ratio) method, to have about equal personal error. Tests conducted by 4 men on a 20-plot series showed a standard deviation of 8.86 percent for the ocular estimate method and 8.38 percent for the height-weight ratio method. In field trials on range grazed by sheep, utilization estimates were about the same when made with either of the two methods.

Statistical comparisons of ocular estimate methods with measurement methods for determining utilization of browse were not found. Apparently, the relationships would be similar to those reported for herbaceous species. One problem typical of browse ranges is that size and growth characteristics of shrubs add to the complexity of determining utilization. This has led to multiple-step approaches. For example, some of the procedures for estimating browse utilization require two or three independent estimates. While the personal error involved in each estimate may be less than for one overall estimate of use, sampling errors of the method probably will be greater.

To obtain satisfactory results, any of the ocular estimate methods require adequate training. Accuracy of results and time required for training depend upon aptitude and experience of the observer as well as characteristics of the vegetation. To promote accuracy, observers should check their estimates with clipped or measured samples at least daily.

Methods Based on Measurement, Correlation, and Regression of Factors Related to Utilization

Height-Weight Ratio

Forage utilization is also assessed by the conversion of some other measurement to weight removal through regression relationships (Lommasson and Jensen 1938). Based on the relationships of weight distribution to height of perennial grasses, numerous charts, tables, and scales have been developed for converting stubble height to percentage of weight removed (Crafts 1938; Collins and Hurtt 1943; Valentine 1946).

After they made comparisons with a weight estimate method, Lomasson and Jensen (1943) concluded that the height-weight principle was

sound and gave more reliable results than ocular estimates if proper procedures were followed. McArthur (1951),[4] studying little bluestem, also obtained consistent results with the height-weight method. Reid and Pickford (1941) tested the method on two perennial grasses and sedge. Standard errors were low, and it was concluded that percentage utilization could be reliably determined if grazing was relatively uniform. Utilization was underestimated by the height-weight ratio method, however, when use was ragged or uneven.

The height-weight ratio method is deficient because the growth form of plants varies with weather, site, and other factors. Caird (1945) reported that errors of 10 to 25 percent may occur if the same height-weight relationships are used each year. Heady (1950) stated that the growth form of a species varied more among sites than from year to year. Clark (1945) found such large variations in growth form due to environmental differences that he concluded that height-weight tables were of doubtful reliability, except for the specific location and season for which they were prepared.

To summarize, the height-weight procedure appears to be an accurate method, but the construction of tables is time consuming and must be done for each condition that significantly affects growth form if satisfactory results are to be obtained.

Stubble-Height Class

Canfield (1944) measured grazed stubble height and lateral extent of different grass species along a 50- or 100-foot line transect and arranged the data by species according to stubble-height classes. Results were summarized to show percentages of each species in the stand, percentage of each species in each stubble-height class, and weighted mean use by stubble-height class. The method was developed for the short-grasses on semidesert ranges in Arizona, but it can be adapted for taller grasses by adding height classes or increasing class intervals.

Stubble-height class data provide clear evidence of grazing patterns. If this technique is combined with consideration of plant weight and form, the method can provide detailed information on herbage removed or residue remaining. Such application would be costly, both in collection and compilation of data. Nevertheless, this method can be of considerable value to the researcher interested in detailed evaluation of use.

Percent of Plants Grazed

This method is based on the mathematical relationship between the weight of forage utilized and the percentage of plants grazed. Thus, percent utilization can be determined from regressions that relate the number of plants grazed to weight removed.

Roach (1950) compared a count of ungrazed plants with the height-weight ratio method on semidesert perennial bunchgrass range in Arizona. The computed correlation coefficient of 0.92 indicated a consistent relationship. In Wyoming, Hurd and Kissinger (1953) compared forage utilization determined by a count of ungrazed Idaho fescue plants and the ocular-estimate-by-plot method; they obtained a highly significant correlation coefficient of 0.92. In comparing the percent-of-plants-grazed method with either ocular-estimate-by-plot or actual weight methods on crested wheatgrass ranges in New Mexico, Springfield (1961) obtained correlation coefficients that ranged from 0.75 to 0.95. All were significant at the 0.01 probability level. To sample equal areas, the percent-of-plants-grazed method took less than 4 percent of the time required by the actual weight method.

Although rapid and simple to use, the method has several inherent weaknesses. Subjectivity is often involved in defining a grazed plant. The method is inaccurate at very low or exceptionally high intensities of use, because, after all plants have been grazed, further use cannot be measured by regression. Also, separate regression lines may be needed for each species or even for different classes of livestock grazing the same species. Comparisons between cattle and sheep on crested wheatgrass showed that, at light degrees of use, cattle graze fewer plants than do sheep (Springfield 1961). Studies in Arizona (Roach 1950) and Montana (Holscher and Woolfolk 1953) showed straight-line relationships between the number of plants grazed and percent utilization. Curvilinear relationships were established, however, by Hurd and Kissinger in Wyoming (1953), and by Springfield in New Mexico.[5]

The percent-of-plants-grazed method assumes that utilization is constant for a given percentage of plants grazed. Curvilinear relationships demonstrate, however, that plants are grazed more closely under the heavier degrees of use.

In a study of perennial grasses in southern Arizona, variation between years in the relationship between percent of plants grazed and percentage utilization by weight was not large

[4] McArthur, James A. B. The use of regression equations to determine utilization of little bluestem. 1951. (Unpublished Ph.D. dissertation on file at Agr. and Mech. College of Texas, College Station.)

[5] Data on file at Albuquerque, N. Mex., field office of the Rocky Mountain Forest & Range Expt. Sta., U.S. Forest Serv.

enough to require separate curves each year for four of the five species studied (U.S. Forest Service 1961). Use of the average relationship would have caused an error exceeding 6.5 percent for only one species when the utilization was 50 percent.

Until more thorough tests are made, the percent-of-plants-grazed method should be used for research only after the relationship has been established for the particular plant and animal species, site, and year.

Other Methods

The *Stem-Count Method*, proposed by Stoddart (1935) for determining utilization of single-stemmed species, served well under specific circumstances but has been replaced by the more versatile percent-of-plants-grazed method. Canfield (1942) proposed a *Short-Cut Method* based on the percentage of grasses grazed to a 2-inch stubble height or less. This method has received little use except in the Southwest, and it does not seem to have any special advantages.

Methods Based on General Observations and Comparisons With Predetermined Standards of Utilization

These methods are based on the general appearance and characteristics of sizable range units and do not require sampling. The general reconnaissance method, which was described by Pechanec and Pickford (1937a), involves an estimate of utilization based on inspection of many factors. Accuracy depends on the experience and judgment of the inspector. The method is not sufficiently accurate for research, and it has been largely replaced as a tool in range management.

Photographic and pasture comparison methods described by Hormay and Fausett (1942) and Bement and Klipple (1959), respectively, are advantageous because the appearance of the range complex can be considered in the appraisal. Both methods can be adapted to a variety of ranges, are easy to use, and require little training. However, neither method is subject to statistical analysis.

In the primary-forage-plant method (Deming 1939) observations are centered on plants that receive the most use. Detailed information, including soil conditions, topography, and degree of grazing, plus abundance, mortality, or reproduction of the principal species, is gathered to indicate quality and condition of the range as a whole. In essence, the same ecological concepts are applied as are involved in classifying range conditions. This method differs from others by providing an answer in terms of correctness of range use instead of percentage utilization.

Prospective Methods

Though methods for determining utilization may be further advanced than our ability to interpret its effects, there is continuing need to increase precision, accuracy, and speed of present methods and to develop new ones.

Shafer (n.d.) recently has worked on the development and evaluation of a twig-count method for determining utilization of woody plants. Although the method was tested only for measuring production, Shafer suggested that twig counting seemed applicable for assessing browse utilization on permanent plots. Presumably, utilization could be determined from regressions that relate the number of twigs browsed to the weight of twigs removed; the principles used are similar to those applied in the percent-of-plants-grazed method.

Shafer suggests an untested refinement that involves clipping browsed twigs near a lateral bud or terminal bud scar, just below the browsed end, to eliminate recounting the same twig at the next inventory.

According to Shafer, the twig-count method is as accurate and four times as fast as clipping and weighing, and is similar in speed to weight estimation. The method does not destroy existing browse, and results can be analyzed statistically. It appears worthy of further development and evaluation specifically as a utilization method. Additional research is also needed to test its applicability to various shrub types.

Recent technological advances have focused attention on electronic instruments for measuring vegetation. The use of such instruments would be primarily to make weight estimates where such estimates are used to determine the utilization. Fletcher and Robinson (1956) reported that a capacitance meter provided satisfactory estimates for dry herbage weight of several plants. They suggested that, by more intensive samplings, herbage production might be more accurately characterized than by weighing clipped herbage, even though individual readings might not be so accurate. Rauchfuss (n.d.) used a capacitance meter called a "vegometer" to estimate weight, and obtained close correlation between herbage weights of Gardner saltbush and instrument readings. Readings could be made as rapidly as weight could be estimated. Turner (1961a, 1961b) used a capacitance meter, referred to as a "densitometer," on Bermudagrass turf and obtained excellent correlation between clipping and instrument measurements during the first 4 weeks of growth, but somewhat lower correlations after that period.

Van Dyne (1960, 1961)[6] tested the capacitance

[6] Personal correspondence with G. M. Van Dyne, January 3 and February 8, 1962.

meter on mature forage in which 1 out of 10 capacitance-measured plots was clipped. Correlation coefficients between clipped and estimated plots ranged from 0.6 to 0.8. Results from tests with succulent vegetation were erratic.

Campbell et al. (1962) detected numerous sources of error in the capacitance principle. They found, nevertheless, that a linear regression existed between the logarithm of meter readings and sample yields in most series of samples. The predictive relationships for series accounted for 90 percent of the variance in yield. These English workers concluded that, if errors are solely random, instrument sampling may prove more efficient than clipping methods, either by achieving the same sampling error in a much shorter time or a much lower error in the same time.

In methods involving forage weight determinations, an accurate and rapid measure of plant moisture in place would be valuable. Phillips (1959) used successfully a tip-sensitive electronic probe called the Delmhorst moisture detector to determine moisture percentage of bryophytes and some other plants. This detector can be used to take readings at the surface and at increments to depths of more than 1 inch. It might be adaptable for measuring moisture content of range plants.

The capacitance meter and moisture probe offer numerous possibilities for modifying or supplanting present utilization methods and techniques. An important advantage of using instruments would be that vegetation on permanent plots could be measured year after year without damage. This feature also would enable measurements of regrowth under a variety of conditions not possible by conventional methods.

METHODS FOR DIFFERENTIATING USE BY DIFFERENT ANIMALS

As demands upon rangelands intensify, recognition and evaluation of use by different animals become increasingly important. Realistic management of the range for any one class of animal must consider the impact of all other occupants. Satisfactory means of distinguishing utilization by different animals are essential to understanding this impact.

Ruminants and Rodents

Use of herbaceous vegetation by one ruminant generally cannot be distinguished from that of another, nor from that of rodents, simply by appearance of the grazed plants. While intraspecific rodent uses of grasses and forbs sometimes can be distinguished, frequently they cannot.

Utilization of woody vegetation is somewhat easier to differentiate. Because ruminants lack upper incisors, they either break woody stems over the lower incisors or chew them off with the molars. These actions impart a stringy or erose appearance to ends of the cropped stems. However, woody stems browsed by different ruminant species often look alike. Differentiation must therefore depend on other evidence, such as height of browsing, part of plant consumed, season of use, fecal deposits, tracks, and known range of species. If two or more ruminants use the same general range, the amount of use attributable to each can be determined with reasonable accuracy only if their food habits differ or the areas or seasons of use do not overlap. On rough, steep parts of the range not grazed by livestock, utilization generally may be ascribed to game (Julander and Robinette 1950). It cannot be assumed, however, that game browsing on rough terrain is necessarily representative of use over the entire range. When seasons of use for different species of animals do not overlap, utilization can be determined after the period of use by each species (Dasmann 1949).

In contrast to ruminants, rodents cut, rather than break, woody stems. This leaves a smooth, slanted surface on the ends. Also, woody stems gnawed by rodents usually bear marks left by the incisors. In differentiating use among rodents, Pearce (1947) found the width of these marks to be a reliable indicator of the responsible species. Knowledge of the rodents that occupy an area also is important in identifying and distinguishing use.

Animal indicators alone are useful primarily for determining food habits or animal abundance. Their value for determining extent of use is more limited. Common methods based on animal indicators include: Direct observations of feeding animals as described by Dixon (1934); stomach analyses; examination of cheek pouch, den, and burrow contents; and feeding of captive animals.

Plant or animal indicators do yield important evidence, but they generally fail to provide a complete or reliable evaluation of forage use by different animals. A better appraisal of utilization may often be made, however, if these indicators are used with livestock-, game-, or rodent-proof exclosures in various combinations. This method involves fenced plots designed to exclude or enclose certain species of animals. When used as enclosures the plots may be emptied of all game, livestock, or rodents; then desired numbers or combinations of animals may be introduced. This is an effective but often costly means of evaluating food habits, effects of grazing on vegetation, or interspecific competition of the animals concerned.

Insects

The many kinds of insects, their diverse habits, wide and sudden fluctuations in numbers, mobility, small size, and short feeding periods make identification and measurement of their use and effects especially difficult. Nevertheless, entomologists do have field and laboratory methods that appear feasible for evaluating insect effects, particularly on browse species.[7]

Leaf-chewing insects often feed on the more succulent parts of the leaves, so that telltale leaf vein skeletons or stems remain. Larger insects such as grasshoppers and Mormon crickets generally remove entire sections of leaves, with a resulting ragged appearance that can be identified by an experienced observer. Pelletlike excrement on the ground and remnants of cast skins that cling to stems and leaves for a month or so after the insects have completed their development are often useful in identifying the source of utilization. The larvae of some species pupate in the soil and can be found by sifting the soil.

Plants affected by sap-feeding insects and mites may be stunted, slightly chlorotic, show necrotic spots at site of puncture, or exhibit twisted and deformed leaf or stem growth. Some mites produce webs that trap visible dust particles; others are gall-formers. Also, the organism, egg shells, and cast skins can be seen with a 10-power hand lens. Cottonlike wax is produced by some aphids, and cast skins persist after the adults have migrated to alternate hosts. Scales may produce a similar wax; thus, one must be discerning when interpreting this evidence.

An untried method for determining utilization of range forage by insects is suggested. An insecticide would be applied to early plant growth in the spring and subsequently at approximately 3-week intervals. A long residual insecticide such as DDT or Dieldrin applied at the rate of 1 pound per acre should limit damage from leaf feeders and some of the borers. A long-lasting systemic insecticide such as dimethoate, applied at the beginning of the growing season and again in July, would control the sap-feeding insects and mites. At the peak of the growing season, a protected sprayed area and a similarly protected but unsprayed area could be compared for production and other characteristics. Differences would be attributable to utilization or other effects due to insects. Sprayed areas should be protected from use by livestock, game, and rodents, and should be no less than 1 acre in size, because insects tend to move in and damage the plants before being killed. Samples for forage production or other characteristics should be taken near the center of sprayed areas to avoid getting a biased sample.

[7] Personal correspondence with Dr. Noel D. Wygant, April 20, 1962.

DISCUSSION AND RECOMMENDATIONS

During the past 30 years or so, many improvements have occurred in experimental design and refinement of sampling techniques for measuring forage utilization, but there has been little advance in basic methodology. Major emphasis has been on percentage removal. Whether this approach is best, or its results are interpreted accurately, is often questioned.

Some workers have suggested that the amount of herbage that remains after grazing is a more satisfactory index to proper range use. Recently, the concept has been advanced that periodic resting of certain ranges will overcome harmful effects of "full" grazing. Grazing management based on this concept may largely eliminate the need to determine utilization. While these and other concepts are being tested and new methods are being developed, however, much current methodology undoubtedly will continue to be used for many years.

Although the amount of forage consumed by animals is difficult to assess, the difference between amounts of grazed and ungrazed herbage offers the best approximation, especially when the movable cage technique is employed. It is not a problem to determine whether use has occurred where samples are clipped and weighed. Light or early use is not always easy to detect, however, and may be ignored by ocular-estimate methods. Amount of photosynthetic tissue or reproductive parts remaining is not considered by methods for determining utilization by herbage weight differences. On shrub ranges where leaves, flowers, or fruit comprise a significant proportion of animal diet or material browsed, measurements of twig lengths alone will result in underestimation of utilization.

Of the methods available, those based on differences before and after grazing or between grazed and ungrazed plots or plants are the most direct. Furthermore, such methods are highly adaptable to statistical analyses. For obtaining weights of grazed and ungrazed plots or plants needed for these methods, clipping is slowest but most accurate for a given plot.

Because of the work of hand clipping and weighing herbage samples, methods based on actual weight have been considered unsuited for sampling large range areas where vegetation is heterogeneous and use is highly variable. Power equipment, however, such as the scythette described by Hedrick and Hitchcock (1953) and modified by McGinnies (1958) or the sheep-shear-

ing head tested by Alder and Richards (1962), greatly speeds up clipping where interest is in total or single-species production.

Where species separation is desired, Van Dyne [8] suggests that machine-harvested samples can be subsampled and hand separated. Direct separation of species in the field, however, should speed the process still more. Toward this objective, Van Dyne [8] has been working on an attachment for an electrical vacuum clipper that may enable fairly rapid separation of species on ranges where discrete plant entities can be identified.

Another major disadvantage of clipping procedures is that they cannot be used on permanent plots because harvesting, in itself, is a treatment.

The weight of the vegetation can be ocularly estimated more rapidly than it can be determined by clipping and weighing, which permits more intensive sampling of the population. If the weight-estimate method is combined (Pechanec and Pickford 1937b) with double sampling, the accuracy of estimates can be approximated and estimates adjusted (Wilm et al. 1944). Double sampling can be applied to any method of determining utilization that permits either measurement or estimation of the same vegetation attribute. Generally, when this technique is used on herbaceous ranges, ocular estimates are made for a number of plots; herbage on certain plots is clipped and weighed, and estimates are then adjusted on the basis of regression analysis. Although seldom used in conjunction with the estimate of twig utilization method, the double-sampling technique is also suited to such application.

The value of methods based on measurement, correlation, and regression of factors related to utilization depends on the degree of correlation between variables. Though generally based on weight, these methods do not provide a measure of herbage produced or consumed; neither do they reflect the influence of regrowth. Although not designed specifically to do so, the height-weight ratio, stubble-height class, and percentage-of-plants-grazed methods provide information concerning the physiological and morphological characteristics of a grazed stand. The percent-of-plants-grazed method is gaining favor, largely because of its speed and simplicity.

Methods based on general observations and comparisons are useful for gross determination of range use. They do not provide for actual measurement of herbage production or consumption, or amount of photosynthetic tissue and reproductive parts remaining. Such factors, however, are generally considered by the person judging utilization. The primary-forage-plant method expresses utilization directly in terms of correctness of range use. Because this method provides such a detailed evaluation of extent and effects of utilization, it deserves more attention than it has received in the past. Pasture-comparison and photographic methods are useful for assessing utilization over large areas.

Electronic instruments may become useful for determining herbage production and forage utilization. Until electronic instruments have been tested more thoroughly, however, it appears that a system of double sampling in conjunction with capacitance readings is the soundest approach. One possibility would be to substitute capacitance measurements for ocular estimates. Pioneering efforts indicate that instrument readings may be more precise than ocular estimates. If so, fewer time-consuming clipped plots would be required to construct regression curves.

Progress in the development of better methods for determining forage utilization depends upon cooperation and coordination of attack by various disciplines. The following recommendations are therefore directed to particular areas of specialization:

Plant physiology.—More needs to be learned about the influence of plant tissue removal on photosynthesis and the reproductive processes of individual plants. Such problems as the effect of utilization on nutrient translocation, root characteristics, and development of fertile or vegetative stems have been recognized and investigated to varying degrees, but more study is needed.

Plant and animal ecology.—Too frequently we fail to recognize, or we simply ignore, forage use by animals other than the ones for which the range is managed. To better interpret plant-animal interrelations, wider application of available techniques, increased emphasis on development of new techniques for differentiating use, and separate records of use by different animals are recommended.

Electronics.—To be most effective, the development or adaptation of electronic instruments for measuring herbage or browse should be through the coordinated efforts of range specialists and electrical engineers. Efforts should be made to develop instruments selective enough to measure individual species and plant parts.

Statistics.—There is a need for verified information concerning the relative accuracy and efficiency of common utilization techniques on even the major plant associations. Additional effort should be directed toward compiling and evaluating experience data and determining the statistical adequacy of methods now in use. This approach should be continued for new or revised methods.

The range researcher or manager, in applying utilization techniques, needs to consider how the

[8] See footnote 6.

data will be interpreted. An awareness of the importance of interpretation leads to selection and development of more suitable methods and techniques.

The most pressing needs for determining and differentiating forage utilization can be summarized as follows: (1) We need to improve criteria for selecting methods by intensively testing the accuracy and efficiency of promising methods on all major vegetation types; (2) we need to pursue more vigorously the development of new ideas in basic methodology—both for determining and differentiating utilization effects; and (3) we need to reevaluate our objectives for measuring utilization so we can better interpret results in terms of plant-animal relationships.

MEASURE OF ANIMAL RANGE USE BY SIGNS

Odell Julander, R. B. Ferguson, and J. E. Dealy

Appraisal of range use by each important animal species and of the effect of this use is extremely important in range and wildlife habitat management. Often the most practical way of assessing range use by wildlife, and on localized areas by livestock, is by signs they leave. This paper discusses four methods of interpretation and attempts to evaluate them:

1. The pellet-group or fecal-count method. This method is emphasized here because it is widely used in determining big-game use of the range.
2. Counts of rodent mounds or burrows.
3. Spot-count sampling and related methods.
4. Track counts.

THE PELLET-GROUP METHOD

Taylor (1930) was first, so far as we know, to record animal signs systematically in order to estimate pressure of foraging animals on the range. He counted rodent dens and rabbit pellet groups and suggested that the pellet count was a promising method of estimating the relative numbers of animals. Ruhl (1932) considered the systematic determination of feces abundance to be a promising method of estimating relative abundance of game in various parts of a large area. Since the early 1940's the use of pellet-group counts for estimating relative abundance of big game, particularly deer, has become widespread.

The pellet-group method may be used for estimating relative intensity of use, trend in use from year to year, or total population of a given area. The most common application is to estimate relative intensity of use of an area by one or more kinds of animals. Intensity of use may be expressed as number of pellets or pellet groups per unit area in order to compare use on different areas or types or for trend in animal numbers. This measure could well be used for any species whose defecation rate is unknown or is highly variable. Pellet or pellet-group counts on sample plots are simply converted to an area basis.

Total populations of deer herds have been estimated with reasonable success by the pellet-group-count method. This is possible only where entire herds occupy known areas for a definite period as migratory deer herds on winter ranges. Average dates of arrival and departure of the main herd are estimated to evaluate herd-days' use of the unit, and the entire unit is sampled for pellet groups.

Current and Other Uses of the Method

In 1961 wildlife management personnel in 15 States reported use of pellet-group counts as a standard big-game management technique, and they indicated that the method supplied useful information. Workers in 16 other States reported experimental trials to determine the feasibility of the method under local conditions. Use of the method in Canada was reported as primarily experimental; however, in Ontario it was used as standard procedure in estimating deer use in yard areas.

The survey showed that nine States and two provinces have used pellet counts as an index of elk abundance. Two States and four provinces have tried the method in studies of moose. Alberta workers used the technique for bighorn sheep and mountain goats, while in New Mexico the method was used in studies of Barbary sheep.

Due to difficulties of determining animal movements accurately and of obtaining samples of adequate reliability, most States and provinces use pellet-group counts as an index to relative use rather than as an index to total population. A few States reported using pellet counts to determine relative range use by two or more big-game species.

Pellet-group counts are widely used by the U.S. Forest Service to determine relative degree of range use by big game. In the Intermountain Region of the Forest Service, pellet-group and cow-chip counts are an integral part of the

range analysis procedure to evaluate current use of the range by game and livestock.

The number of droppings per unit area may be a useful measure of relative abundance of different animals. Riney (1957) in New Zealand used feces counts to estimate relative abundance of several wild mammals, including red and fallow deer, goat, and brush-tailed possum. Robinson and Harris (1960) used the number of coyote scats per mile of trail as a measure of relative abundance on areas where coyotes had and had not been controlled. Results indicated wide differences in coyote numbers on the two areas, and the method appears satisfactory for the purpose. Dropping counts might also be useful for determining relative abundance of other species whose defecation rates are unknown and whose relative populations cannot readily be determined by other means.

Defecation Rates

Since the accuracy of estimating animal-days' use or total populations on a given area depends upon knowledge of the rate of defecation, several workers have studied separate phases of this subject.

Deer.—Rasmussen and Doman (1943), in central Utah, counted pellet groups in a 741-acre pasture stocked with known numbers of deer for a given period. From these data, McCain (1948) derived the figure of 12.7 as the daily defecation rate of mule deer. Also, from data collected by Rasmussen and Doman (1943), we computed the following pellet groups per deer-day for three 1-month periods:

August	11. 12
September	13. 08
October	13. 54
Average	12. 58

Eberhardt and Van Etten (1956), working with penned white-tailed deer in Michigan, counted an average of 12.7 pellet groups per deer-day. The highest rate was 14.6 for deer on a cafeteria diet. Rogers et al. (1958) collected data in three deer-proof pastures over a 5-year period in Colorado and reported an overwinter daily defecation rate of 15.21 (±1.06) pellet groups for uncleared plots and 14.87 (±2.74) for cleared plots. For the 5 different years the averages for uncleared plots were 15.19, 14.32, 16.29, 15.57, and 15.52. These rates are close to those of Michigan white-tailed deer on cafeteria diet. The forage supply was adequate on the Colorado pastures and was apparently equal, in most pastures, to the cafeteria diet in Michigan. Forage in the Utah pasture where Rasmussen and Doman worked was inadequate. For this reason Rogers et al. suggest using a defecation rate of 15 on areas having fair or good forage supplies and 13 on depleted ranges or where diet is restricted. Eberhardt and Van Etten found that both age class and diet significantly influenced differences in rate of defecation.

Elk.—Melvin Morris of Montana State University (correspondence in 1954) reported our only record of defecation rate for elk. Average defecation rate for 5 cow elk and 5 calf elk during a 3-day period was 11 pellet groups per elk-day.

Moose.—Vozeh and Cumming (1960) reported a defecation rate of 13 pellet groups per moose-day based on unpublished data collected by R. Y. Edwards in Wells Grey Park, British Columbia.

Barbary sheep.—Ogren (1959) reported 12.7 pellet groups per day as the mean defecation rate for a group of 10 Barbary sheep over a 4-day period.

Domestic sheep.—Longhurst (1954) reported a defecation rate for domestic sheep of 13.3 on dry feed and 15.5 on green feed.

Cattle.—Fuller (1928) found that dairy cows excrete about 12 times per day regardless of breed. Waite et al. (1951) reported daily excretions ranging from 9 to 13, with an average of 12. Defecation rate changed little from day to day or throughout the grazing season. Johnstone-Wallace and Kennedy (1944) and Peterson et al. (1956), both observing dairy cows on pasture, determined defecation rates of 12 per cow-day. Julander (1955), from cow-chip data collected from two 100-acre crested wheatgrass pastures in central Utah, determined an average of 11.4 cow chips per cow-day. The lower rate in Utah might have been due to less succulent forage than that on the Eastern pastures.

Rabbits.—The rate of pellet defecation by cottontail rabbits varies widely. Tripensee (1938), Hendrickson (1939), and Dalke (1941) reported rates of 266, 320, and 491, ±20 pellets per day, respectively. Cochran and Stains (1961), using five to eight rabbits in each test, found that defecation rates for individual rabbits varied widely with diet, and between trials. On soybean feed the rate was 486 ±8.3, on alfalfa it was 455 ±5.3, and on corn it was 54 ±6.2. They concluded that aging of pellet groups seemed impossible and that present techniques were highly inaccurate, but they did indicate that the method had some value as an index to populations.

Arnold and Reynolds (1943), working with penned Arizona and antelope jackrabbits in Arizona, observed a defecation rate of 513 ±27 pellets per day. They found no significant difference due to age, weight, sex, species, or green and dry native forage. They reported a close linear relationship between weight of forage consumed

and weight of feces. In addition to determining relative populations by pellet counts, they suggested the possibility of determining the amounts of forage removed by means of pellet weights.

Reliability of the Pellet-Group Method

Reliability of the pellet-group method can best be determined by comparing results from pellet-group sampling with known numbers of animals. Comparison of results with those from other proved methods may be useful where actual numbers of animals are not known.

Comparison with other methods.—McCain (1948) computed from pellet-group counts 12,600 deer on a 310,600-acre winter range. Road-strip samples gave an estimate of 12,400 deer in the same area. Couey (1951) compared results from deer-pellet counts with those obtained concurrently with the Lincoln Index Method in the Kootenai area of Montana. The pellet-group count resulted in an estimated deer population of 7,215; the Lincoln Index estimate was 7,250. Julander and Robinette (1950), in determining the population of a deer herd in Utah, reported that the pellet-group method was less variable than other methods (Lincoln Index and kill records plus differential herd composition).

Vozeh and Cumming (1960) compared the population of moose on an 875-acre area in Ontario as derived from aerial counts with the population calculated from a pellet-group survey. The mean aerial count in each of 2 years was within the 95-percent confidence limits of the number determined by pellet-group count.

Though methods listed above provide no measure of deviation from actual populations, close agreement of their results does promote confidence.

Comparison of estimates by pellet-group counts with known numbers.—Ryel (1959) concluded that accurate population estimates can be made by using the pellet-group method, provided the method is properly applied. Ryel's report was based on data from the George Reserve, a fenced area of 1,100 acres in southern Michigan with a known deer population. Harris (1959) estimated the population of deer on a 4,544-acre area of winter range in Colorado in 1958 and 1959. He concluded that pellet-group counts, which indicated 305 deer in 1958 and 381 deer in 1959, substantiated a known increase in population. However, the change shown by pellet-group counts on the 0.01-acre plots was about 18 percent too low.

Sampling Pellet Groups

One difficulty in using the pellet-group method in administrative work is the time required to obtain an adequate sample. Rogers et al. (1958), working in 90- to 160-acre fenced areas in Colorado, suggested that 13 to 19 line-plot transects of 25 plots each (0.01 acre per plot) and 12 to 23 transects of 40 plots each (100 square feet per plot) are needed to sample pellet groups with reasonable accuracy. Their data indicate that intensity of sampling should be increased as density of pellet groups decreases.

Ryel (1959), in a 1,100-acre fenced area with a known number of deer, obtained reliable estimates of deer 4 years out of 6 by sampling only 4.4 acres (table 1). Eleven stratified, random, line-plot transects with 1/50-acre plots were used.

TABLE 1.—*Accuracy of estimate of deer, by pellet count and sampling 4.4 acres of a 1,100-acre fenced area, for 6 years*

Year	Number of plots	Total pellet groups	Mean pellet groups	Estimated deer per square mile	Known deer per square mile
1953	243	533	2. 1934	[1] 30. 88(23. 58 to 38. 18)	33. 06
1954	235	483	2. 055	28. 45(20. 85 to 36. 05)	38. 46
1955	241	285	1. 182	[2] 17. 32(13. 52 to 21. 12)	39. 58
1956	221	769	3. 480	54. 12(43. 62 to 64. 62)	32. 26
1958	249	649	2. 606	38. 85(24. 68 to 53. 02)	41. 40
1959	268	598	2. 231	33. 60(21. 88 to 45. 32)	33. 02

[1] Confidence limits of two standard errors.
[2] A recheck of plots in 1955 gave 37.62, indicating the above count for that year was too low.

Vozeh and Cumming (1960) reported satisfactory results by counting moose pellet groups on 1/10-acre plots along systematically spaced lines and by sampling 0.9 percent of an 875-acre area.

Julander (1955) reported fairly consistent results from cow-chip counts in two 100-acre pastures at Benmore Experimental Range in Utah. Results from 0.01-acre plots on restricted-random line-plot transects were as follows:

	Transects (number)	*Plots per transect (number)*	*Cow-day use*	*Cow-chips per cow-day (number)*	*Standard error*
Pasture A	34	10	1, 401	11. 21	0. 64
Pasture B	8	15	1, 062	11. 62	1. 32

The original data suggest that about twelve 10-plot transects would be necessary to sample such areas with 0.01-acre plots; the sampling error would not exceed 10 percent of the mean. The Benmore range is gently rolling, and cattle use was reasonably uniform. Sampling cow chips on most mountain ranges would be much more difficult than sampling on those pastures.

Pellet groups are seldom distributed at random. Data from small individual circular or rectangular plots have definite Poisson distribution. For this reason line-plot transects, which are essentially long-segmented plots, are frequently used as sampling units in pellet group work. Peterson et al. (1956) reported that for 1- to 3-year periods dairy cattle excretions on pasture may be estimated with reasonable accuracy by the Poisson distribution function. Descriptions of sampling procedures have been published by Bennet et al. (1940), McCain (1948), Dasmann et al. (1955), Eberhardt and Van Etten (1956), Riney (1957), Robinette et al. (1958), Rogers et al. (1958), Harris (1959), Vozeh and Cumming (1960), and others.[1]

Robinette et al. (1958) preferred circular plots to rectangular plots because of greater speed in taking samples, greater ease in defining plot boundary, and because one man can run a circular-plot survey. They recommended 100-square-foot plots or 0.01-acre plots divided into two bands on which counts are made clockwise and then counterclockwise to avoid missing pellet groups.

Problems in Using the Pellet-Group Method

Use of the pellet-group method for estimating animal populations or population trends requires that the entire seasonal range of the grazing animals be sampled. Animals may alternate from high to low winter range in different years. Unless a transect extends entirely through the winter range or the entire range is sampled in some way, the data may indicate only that deer may have grazed the sampled part of the range differently in different years. Only after limited sample areas have been shown to truly reflect deer use of the entire range can sample counts on limited key areas be considered reliable.

Usefulness of the pellet-group method for determining forage removal from a given part of range may vary greatly with class of animal. Vozeh and Cumming (1960) found that, on the basis of pellet groups, moose made more use of the conifer type than browsing indicated and implied that moose leave a portion of their daily droppings in areas used primarily for shelter. This is certainly a serious problem in sampling fecal droppings of cattle and domestic sheep. Droppings of those animals are concentrated at bed grounds and shading areas. In contrast, deer leave their droppings primarily where they feed and seldom on bed grounds. In Utah pellet-group counts usually indicate greater deer use than is indicated by forage utilization estimates.

Inability to measure all forage used (such as ephemerals in spring, early growth masked by later growth, and fallen leaves of aspen and other trees and shrubs) might be responsible for this difference. In such cases pellet-group counts may be more accurate than forage utilization estimates in estimating actual forage removal from a given area. Julander and Robinette (1950) used a combination of dropping counts and forage utilization to map intensity of use by deer and cattle on an entire deer-herd unit. Cumming (1961) used both pellet-group counts and browse utilization to evaluate deer use of winter yards. Several State agencies now use pellet-group counts in conjunction with browse utilization surveys to evaluate big game use of the range as a guide to management practices. This gives a much more complete basis for deer-herd management than do pellet-group counts alone.

Type of vegetation sometimes creates problems peculiar to individual ranges. For example, where deciduous trees and shrubs occur, fallen leaves often cover pellet groups. However, leaf fall may be used to advantage when it occurs within a short period. Mean date of leaf fall can be used as the beginning of the time interval that must be known in computing annual population from the number of pellet groups. Variable leaf fall within some forest types or the shifting of leaf cover by wind, however, may hinder the finding of pellet groups. Dense herbaceous vegetation in many areas makes the finding of pellet groups virtually impossible.

Deterioration of pellet groups is another factor that varies from region to region. Wet, humid climate speeds decomposition. Dry, semiarid climate tends to preserve them. Even within climatic zones, decomposition rate is affected by or related to amount of vegetation, slope and aspect of topography, animal diet, and class of animal. This problem is basic to the use of pellet-group counts. It is a local problem that needs to be solved for each specific area. Physical destruction of pellet groups also must be considered. On steep terrain, heavy rainfall may wash away or redistribute groups so they are no longer distinguishable (Wallmo et al. 1962). Insects may destroy pellets (Ferguson 1955) and (Robinette et al. 1958), and in areas of high animal density

[1] Ferguson, Robert B. The pellet group count method of censusing mule deer in Utah. 1955. (Unpublished master's thesis on file at Utah State Univ., Logan.)

trampling must be considered. Again, these may be local problems with which each worker must be familiar.

The difficulty of distinguishing recent groups from old groups has been mentioned often. Cochran and Stains (1961) stated that visual aging of rabbit pellets seems impossible. Most workers have solved this problem by clearing sample plots or by marking present groups at the time of observations on permanently located plots. This procedure, however, cannot be followed when temporary plots are used, and it adds to the time required to obtain data. For these reasons, game managers are continuing to search for criteria for determining the age of pellet groups. In semiarid regions age determination is not believed to be a great obstacle (Ferguson (1955), Robinette et al. (1958), and Rogers et al. (1958)). However, even in semiarid areas pellet groups are difficult to age in wet weather. Pellet groups that are strewn out need careful defining if total animal population is to be estimated accurately.

Distinguishing between droppings of different animals on the same range is sometimes difficult. This is particularly true for deer and domestic sheep on winter range, and for deer, antelope, and bighorn sheep on common-use range.

COUNTS OF RODENT MOUNDS OR BURROWS

Biologists usually determine relative abundance of small rodents by systematic trapping and by expressing the results as the catch per trap-night or for a short period. If they want an estimate of population, animals are live-trapped, marked, released, and retrapped (Lincoln Index method) or, more often, they are completely trapped from sample areas. Reynolds (1958) used snap-trap transects to determine populations of kangaroo rats per acre. From 12 to 15 transect lines of 10 snap-traps for three successive nights were needed to give an accuracy of 10 percent of the mean with a probability of two chances out of three. Since trapping methods require considerable time and experience, some workers have turned to the more rapid method of mound or den counts as an index to relative rodent populations.

Fossorial rodents, such as pocket gophers, are seldom seen and leave few or no droppings above ground to be counted. Ground squirrels, mice, kangaroo rats, and other important range rodents are likewise difficult to census.

Taylor (1930) used den counts on ½-acre plots and belt transects to determine the relative density of kangaroo rats, wood rats, ground squirrels, and smaller rodents on the Santa Rita Experimental Range in Arizona. That method apparently was satisfactory for measuring the relative abundance of the various rodents in different types. Julander et al. (1959) used mound counts on 0.01-acre plots and the presence of casts on 1-square-foot plots to indicate the relative density of pocket gophers in comparing seeded areas in Utah where gophers had and had not been controlled. Keith et al. (1959) used counts of new mounds thrown up during a 48-hour period on extensive 6-foot-wide transects to compare with trapping results as a measure of relative gopher abundance on areas of sprayed and unsprayed vegetation. Though they did not compare accuracy of the two methods, these authors suggest that the larger sample obtained by the mound-count method may have been more representative of the area than the count obtained by trapping.

Howard (1961) estimated pocket gopher populations in California by two methods: (1) Counting burrow systems and assuming each system to represent one pocket gopher; and (2) counting mounds on transects 20 feet wide (10 feet in dense cover) and at least 1,000 feet long. Each time a fresh mound was found no more were counted in the next 5 yards. The number of mounds counted represented the approximate number of gophers in the area occupied by the transect. Both methods, when used shortly after or during a period of considerable gopher activity, were reliable in indicating relative changes in populations from year to year. However, the burrow-system-count method was not satisfactory in areas having dense gopher populations because individual systems could not be recognized.

Several factors limit the accuracy of the gopher-mound count as an index to population. Availability of food, soil conditions, differences in activity of gophers at various seasons as affected by weather conditions, and possibly other factors influence gopher tunneling and hence the number of mounds. Little information is available on the relation of number of mounds to gopher numbers. Crouch (1933) concluded that mound counts were not a reliable index of pocket gopher burrowing activity. He found that gophers burrowed deep when soil surface was dry and suggested that they may then deposit excavated soil in unused tunnels instead of bringing it to the surface to form mounds.

Miller and Bond (1957) found that the number of mounds per gopher per day varied greatly with season of year. The periodic averages ranged from 0 to 2.9. Seasonal trend in number of mounds seemed to represent seasonal changes in breeding behavior and feeding habits.

Current studies in Utah indicate that correlation is good between mound counts and number of

pocket gophers trapped and that mound counts, accumulated over a period of several weeks, may provide a reliable index of gopher population.

SPOT-COUNT SAMPLING

Various methods of determining game bird densities by spot sampling have been used. These include counts of crowing, drumming, and calling from specified locations along a sampling course. Counts of birds on dancing or singing grounds during the breeding season have often been used to determine relative numbers or trend in numbers (Mendenhall and Aldous (1943); Dorney et al. (1958); Lowe (1956); and Mosby (1960)).

J. Edward Dealy, a coauthor of this paper, has developed a nightlight spot-counting technique for determining seasonal use by deer from different habitats. This method is particularly well suited to forested areas in which logging has created openings. Such openings tend to attract deer and facilitate counts. From selected observation points near the openings or at other favorable areas along a predetermined route, systematic night counts are made with the aid of a spotlight. Eye reflections are easily seen up to one-fourth mile, and accessible areas can be searched thoroughly in a short time. Deer are little disturbed by an observer with a spotlight in an automobile.

By this method, Dealy determined the preference of deer for various habitats at different elevations, on different slopes, and during different seasons and years. The determinations were made on the H. J. Andrews Experimental Forest in Oregon. For studies of seasonal habitat preference, semiweekly observations are recommended. For population trend studies that extend over the entire season, biweekly samplings appear adequate. This method may be suitable for determining deer populations where the pellet-group method is impracticable. However, it needs further testing to determine sources of error and its reliability.

TRACK COUNTS

Track counts have been used with some success as a rough measure of the size of migrating big-game herds in California, Colorado, Idaho, and other States. Snow-covered or dirt roads are swept with brush drags or harrows, and the number of tracks crossing the roads are counted. Counting each individual deer track is difficult. Results of successive track counts of a single migrating game herd have varied widely between days and years, apparently because of weather conditions and possibly because of other factors. Hunter and Yeager (1956) concluded that in Colorado counts of deer in meadows were as good as track counts and cost only about 5 percent as much.

The usefulness of track counts as a measure of relative range use of big game on a particular area has not yet been satisfactorily demonstrated.

CONCLUSIONS

The Pellet-Group or Fecal-Count Method

The usefulness and accuracy of the pellet-group method for determining the relative abundance of animals and seasonal trends in animal numbers are subject primarily to overcoming difficulties of sampling and proper determination of age of pellet groups and proper application of the method during favorable seasons. When the method is used for determining total populations, defecation rate and length of time animals occupy an area must be known. When these requirements have been met, the method has been successful and useful, particularly for determining relative range use and trend in the number of big-game animals.

The following procedures are recommended on the basis of present knowledge:

(1) Use a randomly located line-plot transect as the statistical unit of measurement. Locate several circular plots at fixed or restricted-random intervals along each transect. Each plot should contain 100 square feet or 0.01 acre. Make two counts, one clockwise and the other counterclockwise, to avoid missing pellet groups, particularly on 0.01-acre plots.

(2) Count pellet groups at the most favorable time, generally when plant growth, leaf fall, or disturbance from various sources are least likely to interfere with counts.

(3) Mark plots permanently and clear or paint pellet groups at the beginning of study where age determination of pellets is difficult and when a definite period of use is desirable and not otherwise obtainable.

(4) Estimate forage use along with counting fecal droppings to aid in interpreting range use. This is especially important where livestock or other animals deposit a disproportionate share of their droppings at resting grounds.

(5) For trend studies on winter range, sample several elevations and aspects of the seasonal range to account for differences in use during open and severe winters.

(6) For determining relative use of the range or relative numbers of deer, use defecation rates of 13 pellet groups per day for severely depleted range and 15 per day for range with adequate forage. Actually, defecation rate for these uses is not extremely important, and an approximate figure for any animal could be used. However, in determining total populations, the defecation rate is important.

(7) Sample intensively enough to obtain acceptable experimental errors. Inadequate sampling may waste time.

(8) Train inexperienced men in determining age of pellet groups until they become proficient.

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Mound or Burrow Counts

Experienced biologists apparently can satisfactorily estimate low populations of pocket gophers and perhaps other fossorial rodents by counting burrow systems. However, this method is not reliable in estimating dense populations. Although the relation of mound to animal numbers is poorly understood, mounds are believed to provide a relative index to animal numbers if counted during definite periods of burrowing activity.

Spot-Count Sampling

Spot-count sampling can be used with proper precautions for determining relative numbers or trend in numbers of game birds. The nightlight spot-counting technique appears useful in determining seasonal patterns of deer use of different habitats, particularly where the pellet-group method is not suitable.

RESEARCH NEEDS

Use of signs in estimating animal use of a range has many limitations and shortcomings. This may be due to lack of knowledge of basic principles and information necessary to use signs effectively. Use of sign methods has advanced much faster than basic information has become available.

Wildlife managers throughout the Nation have emphasized a great need to refine the pellet-group method. Additional research is needed to determine accurately the defecation rates for the various wildlife species. Determination of influences of season of year, composition of diet, and age of the animal on defecation rate would promote greater confidence in the method and greater accuracy in estimates of range use and population trends.

Studies of sampling design and sampling intensity are needed to aid in more efficient sampling. This is especially true where animal population levels are low and where dense vegetation makes finding of pellet groups difficult. Research on the relation of pellet-group density to forage utilization is needed to determine whether pellet-group counts might measure range use more accurately than utilization estimates alone.

Can we relate fecal counts or weights to actual forage removal for other species as suggested for rabbits by Arnold and Reynolds (1943)? Is there a definite relation between percentage of droppings left at resting areas and feed grounds and the percentage of time actually spent on those areas? If so, sampling could be simplified, and interpretation of dropping counts would be more meaningful—particularly for sheep, cattle, and perhaps for many species of wildlife.

Pellet decomposition rates, physical destruction of pellets, criteria for distinguishing the age of pellets, and specifications for counting strewn-out pellet groups are problems needing local or regional study.

Effects of rodents on range and wildlife habitat have received greater emphasis in recent years. In the use of mound and den counts, we need to know: (a) The relation of mound numbers to actual animal numbers; (b) effect of soil, vegetative cover, moisture, season of year, and other factors on number of mounds or dens per animal, and (c) sampling designs and sampling intensities needed to evaluate mound and den densities under various conditions.

Suggested Studies

1. Relation of the number of fecal droppings on resting areas and on feeding grounds to time spent by animals on those areas. What is the defecation rate per animal day for livestock while feeding and for other animals that concentrate their droppings at resting areas?
2. Factors affecting defecation rate of important range animals: Composition of the diet, animal age, season of year.
3. Pellet weight as a measure of range use and forage removal.
4. Relation of fecal numbers to populations of game birds, such as the sage grouse, and of range rodents other than fossorial rodents.
5. Relation of populations of pocket gophers to numbers of mounds and winter casts; relation of mound formation to season of year and other factors; and development and testing of other indices to gopher populations, such as the number of opened burrows closed overnight. At high elevations a study of numbers of winter casts in relation to gopher numbers is advisable. Winter casts are clearly distinguishable and may not be affected by so many factors as mounds are.
6. Efficient designs and methods for sampling pellet groups.
7. Criteria for determining age of pellet groups, specifications for delimiting strewn-out groups, determination of pellet decomposition rates, and investigation of the best seasons of year for making counts.
8. Identification of animal droppings that are difficult to distinguish: Domestic sheep, bighorn sheep, antelope, and deer.

EVALUATION OF THE RESPONSES OF INDIVIDUAL PLANTS TO GRAZING

DONALD A. JAMESON [1]

COMPARISON OF CLIPPING WITH GRAZING

The advantages and disadvantages of using clipping studies to simulate grazing have been reviewed by Culley et al. (1933),[1] who listed the following limitations of clipping: (1) Livestock pull and break off forage at random heights, rather than at uniform heights, (2) species preference of animals is not considered, (3) there is no trampling effect, and (4) the litter accumulations are different than those of grazing. In spite of these limitations, the authors concluded that clipping studies can be used to gain much information.

Other disadvantages of clipping are that (1) the amount of herbage removed is often much greater than could or would be achieved through grazing, and the effect of clipping is therefore more severe, (2) grazing animals select particular plant parts rather than harvesting wholesale as is usual with clipping and mowing, and (3) an individual plant is not necessarily grazed continuously even though the pasture may be. When the amount and kind of forage removed is the same, grazing is probably more harmful than clipping, according to comparisons by Gossett (1961) and Bryant Blaser (1961).

EFFECT OF HERBAGE REMOVAL ON ABOVE-GROUND PARTS OF PLANTS

Dry-Matter Yield

General

Grasses.—The effect of clipping on dry-matter yield has been investigated by many workers. Clipping has reduced the dry-matter yield where a single species rather than a mixture of species has been treated, and the more frequent and severe the clipping the more dry-matter yield is depressed. Ellison (1960) concluded that any clipping would not be beneficial to plants.

Studies of clipping effects on dry-matter yield usually include one to three different heights of cutting combined with several frequencies of cutting. The frequency is variously defined by a predetermined interval of time between treatments, or cutting is repeated when the regrowth reaches a predetermined height or growth stage. Cutting when regrowth reaches a predetermined height or growth stage seems to have considerable merit when the objective is to determine desirable practices of harvesting hay. Cutting at specified time intervals may be more useful for designing grazing systems.

Clipping studies may be criticized because of the use of extreme treatments. Very often plants are clipped to heights much lower than they are normally grazed, and the results have been interpreted in terms of grazing effects. For example, Lang and Barnes (1942) clipped grasses to ground level five or six times in one season.

Modified interspecific competition may greatly influence results from clipping and grazing treatments. For example, clipping studies by Lang and Barnes (1942), Johnson,[2] and Stickler and Johnson (1959) were conducted in mixed plant populations. In these instances it is impossible to tell whether a plant response under a clipping treatment is a direct result of the clipping treatment or is a result of modification of the competition it receives from associated species.

Another possible error in clipping studies is the effect of weathering on dry-matter yields. Turner and Klipple (1952) obtained greater yields from blue grama (*Bouteloua gracilis*) clipped more than once than clipped only once at the end of the season. They suggested that weathering when the plants were left uncut for the entire season was the cause. Weight of the aboveground parts could also be reduced because of translocation to the roots.

Clipping may increase yields the first year, or the detrimental effects of clipping may increase with repeated treatments over successive seasons. Delayed responses seem to be most common in low-growing grasses, particularly blue grama, buffalograss (*Buchloe dactyloides*) and Kentucky bluegrass (*Poa pratensis*).

Results of clipping at various times during the season have not been clear, and generalizations are difficult. Hedrick (1958) concluded that too early removal of herbage was more harmful than later removal. Stoddart (1946), on the other hand, found for bluebunch wheatgrass (*Agropyron spicatum*) that the date clipping ended was more important. He concluded that enough time should be left after the last defoliation for the plant to replenish its carbohydrate accumulation before the end of the growing season. The wide variety of results indicates the need for

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[1] The author acknowledges the assistance of B. R. McConnell and W. F. Mueggler, range conservationists with the Pacific Northwest and Intermountain Forest and Range Experiment Stations, respectively, in the preparation of this paper.

[2] Johnson, Ross E. The effects of clipping on yield, basal cover, and growth of three pasture types in west-central Kansas. (Unpublished master's thesis on file at Fort Hays Kans. State College, Hays, Kans.) 1957.

careful descriptions of temperature, moisture, and plant development, if effects of season are to be established.

Although most evidence indicates clipping reduces yield, a few results to the contrary exist. Canfield (1939) found clipping to 4 inches encouraged growth and increased yield of tobosa grass (*Hilaria mutica*). Driscoll (1957) found that removal of 20 to 60 percent of the herbage of elk sedge (*Carex geyeri*) for 4 years had no effect on dry-matter yield. Cooper (1956) found no effect of clipping at 2, 4, and 6 inches for 4 years in a native meadow in Oregon.

Greater yields from more frequent clipping than less frequent clipping have been reported. Dodd and Hopkins (1958) found greater yield from blue grama clipped five times than three or four times. Heinrichs and Clark (1960) found *Elymus junceus*, *Agropyron cristatum*, and *A. riparium* produced more when cut at 6-week intervals for 5 years than at 3- to 8-week intervals.

Grass-Legume Mixtures.—Some moderate clipping of grass-legume mixtures generally gives greater yields than lighter or more severe clipping. Kennedy (1950) has reviewed the older literature on cutting grass-legume mixtures and concluded that closer clipping generally favors the legumes to the detriment of the grasses in the stand. The legumes that are favored may produce more than the grasses. His conclusion has been substantiated by more recent work.

Shrubs.—Undesirable effects of clipping and grazing shrubs have generally been in proportion to the degree of clipping, although shrubs apparently are more resistant to grazing damage than other plants. Daubenmire (1959) states that shrubs are less easily injured by browsing than herbs because browsing is generally confined to new growth of shrubs and removes but a small part of the shoot.

Invigorating effects of herbage removal have been reported for a number of native shrubs, such as cliffrose (*Cowania stansburiana*), bitterbrush (*Purshia tridentata*), mountain-mahogany (*Cercocarpus* spp.), and rabbitbrush (*Chrysothamnus nauseosus*), by a number of different workers (reviewed by Ellison 1960).

Relationship of Dry-Matter Yield to Physiological Processes

Competition for Light—the Leaf Area Index.—For a plant to grow, total photosynthesis must exceed total respiration. Not only must the plant have positive net photosynthesis during the daytime, it must have a positive net photosynthesis when the night hours are also considered (Curtis and Clark 1950). In growing plants it is possible that the shade produced by a plant or its neighbor will lower the light intensity reaching the lower leaves to a point where net photosynthesis of these leaves is negative. Since part of the plant then uses more food than it produces, the total production of the plant is reduced.

Productivity of most crops increases as leaf area increases and more light is absorbed for photosynthesis. Leaf area is usually expressed as the leaf area index (LAI), which is the ratio of leaf area to ground area.

The significance of leaf area has been reviewed by Donald and Black (1958) and Watson (1952, 1956). Production increases with leaf area until light becomes limiting to the growth of lower leaves and production declines. If the LAI is below the point of maximum yield, production will be reduced by defoliation since productivity depends on leaves to intercept light. If the LAI is beyond the point of maximum yield, however, defoliation will reduce the LAI and productivity will be increased.

On arid and semiarid ranges, it is probable that light is not limiting to grass stands. It may become limiting, however, and total yield may actually be depressed by excessive plant material on meadows. This may partially explain why improved production due to clipping is more common on hay meadows and other mesic situations than on the more arid western range.

Apical Dominance and the Growth of Lateral Buds.—Stem apices inhibit growth of lateral buds in many species, and when the apex is removed the laterals develop. Although the phenomenon has been recognized for many years, investigators working with grasses did not seem to be aware of apical dominance until recently. Stapledon and Milton (1930) showed that, with orchardgrass, plucking the heads increased the number of tillers.

The earlier concept of grass growth was that the leaf elongated continuously from the base of the leaf. It has been shown, however, that elongation of a mature leaf after clipping is slight and that most regrowth comes from elongation of newly formed leaves or from development of axillary buds.

Ellison (1960) concluded that reduction of tillering by clipping is the general case. In most clipping studies the differential effect of removal of stem apices and leaves has not been considered, and it is very probable that had plant parts been considered, the results would not have been inconsistent with present knowledge of apical dominance. Leopold (1949) pointed out specifically that the stem apex inhibits growth of lateral buds in grasses. He destroyed the apices of barley and teosinte without damaging the leaves, and this treatment allowed the lateral buds to elongate into tillers.

Cook and Stoddart (1953) found that deheading crested wheatgrass allowed tillers to develop, and Jameson and Huss (1959) found that the removal of elongated stems of little bluestem resulted in an increase in the number of elongated axillary buds.

Ability of plants to survive may be reduced by removing the apex. Branson (1953) postulated that species of grass with elevated growing points that can be removed by grazing are more susceptible to grazing damage. Aitken (1961) found that oat varieties which recovered poorly from grazing were those with early internode elongation; those which recovered well had later internode elongation.

There are two general hypotheses regarding the growth of lateral buds (Gregory and Veale 1957). The older hypothesis considers nutrients to be the main factor in controlling the growth of laterals. According to this hypothesis, more tillers will arise when nutrient levels within the plant are high. The stem apex can successfully compete for nutrients and thus suppress the growth of laterals. The newer hypothesis is one of hormone control on the growth of laterals. According to this hypothesis, the apex of a stem inhabits the growth of laterals; when the apex is removed, the hormones produced by the apex are no longer available to inhibit the laterals.

Both hypotheses of apical dominance have considerable evidence in their favor, and both should be considered when interpreting clipping studies. Many writers have considered only the nutrient hypothesis.

In recent years there has been considerable study of the possibility that some hormone other than auxin overcomes the effect of auxin inhibition when lateral buds elongate. A naturally occurring compound that promotes bud elongation is the substituted purine, adenine. In most studies of bud promotion, a synthetic purine, kinetin, has been used instead of adenine because of its greater activity.

In general the reactions of lateral buds to kinetin, auxin, and carbohydrates are as follows:

$$\text{no sprouts} \;\begin{array}{c} \xrightarrow{\text{carbohydrates}} \\ \xrightarrow{\text{kinetin}} \\ \xleftarrow{\text{auxin}} \end{array}\; \text{sprouts}$$

Plant Form

Grazing or clipping results in reduced plant size. Peterson (1959) compared plants from areas that had once been heavily grazed with plants from protected areas and found that heavy use resulted in plants with more shoots and less total height growth. Hickey (1961) found that the growth form of crested wheatgrass was more perpendicular on ungrazed areas, but with increased grazing the growth form tended to be horizontal.

Clipping or grazing of shrubs commonly produces a hedged plant. The hedging may protect the remaining plant against further grazing damage.

Protein Yield

In range work, both the total value of feed produced and the dry-matter yield are of concern. Protein content is one of the most common expressions of forage value. Generally, figures given for protein are "crude protein" obtained by multiplying the nitrogen content of the feed by 6.25. Although this is a close approximation, the proper conversion factors may vary from 5.8 to 6.4 (Morrison 1959).

The decrease in percent of crude protein in herbaceous plants with advancing maturity is a well-established relationship (Heady 1961) and needs no elaboration here. Even shrubs decline in protein content with seasonal advance, but shrubs do not generally decline so much as grasses (Oelberg 1956).

Cutting usually results in a higher percent of protein in the forage. Oyenuga (1960) found that the percent of protein was lower when the intervals between cutting were longer, and Knox et al. (1958) found that frequent clipping reduced lignin and improved forage digestibility.

Although the decline of the percent of protein with maturity and the increase of protein content with clipping or grazing are valid generalities, the total yield of protein as a result of various treatments is less clear. Jackobs (1952) found that dry-matter yield and percent of nitrogen are inversely related. The problem then is to arrive at a compromise harvesting system where the increase in the percent of nitrogen offsets the decrease in dry-matter production in such a way that protein yield is maximized. The general evidence from a number of studies is that clipping increases protein yield.

Seed Production

General

Removal of herbaceous parts of a plant adversely affects seed production. The intensity of this effect depends upon the amount of removal, the frequency of removal, and the period in the growing season when removal takes place. Although most investigations of these factors have been confined to cultivated crop and forage plants, the basic principles suggested probably apply to native forage species as well.

Finnell (1929) reported that grazing after shoot development reduced the number of heads, but that grazing before did not. Hubbard and Harper (1949) and Gardner and Wiggans (1957) pointed out that it is not the time of grazing that is critical, but whether the floral primordia is elevated enough to be grazed off. Removal of the floral primordia will greatly delay or prevent seed production. Pauli and Laude (1959) reported that, when the leaves are removed without damaging the seed stalk, earlier defoliations actually cause more reduction of seed yield than later defoliations.

Garrison (1953) and DeBano [3] both found that clipping shrubs decreased flower production even though vegetative growth was stimulated.

An exception to the general detrimental effect of herbage removal on seed production is that of big bluestem (*Andropogon gerardi*). In separate studies by Curtis and Partch (1950), Ehrenreich (1959), and Kucera and Ehrenreich (1961), the burning of big bluestem plots resulted in a marked increase in seed stalk production the following year. The increase in seed stalks may be a result of increased nitrogen availability following burning.

Although in most clipping studies, herbage has been removed without discriminating between plant parts, or at best leaves have been separately treated from stems, a study by Archbold (1945) showed that even the different parts of the stems have different importance in their effect on seed yield. She found that shading the ears was more effective in reducing the weight of the ears than was shading the leaves or stems. By similarly shading or removing various plant parts, Watson et al. (1958) calculated the following contribution of various parts to the grain yield: Awns, 10 percent; ears except for awns, 16 percent; flag leaf, including lamina, sheath, and peduncle, 59 percent; sheaths and leaves below the flag leaf, 15 percent.

Archbold and Mukerjee (1942) concluded that carbohydrates from the roots of barley could not account for more than 11 percent of the gain in weight of aboveground parts, and that there was similarly little transfer from stored carbohydrates in the aboveground part of the plant to the developing fruit.

Experiments with clipping and shading have been supported by studies with translocation of carbon 14 by Kravtsova (1957) and Mayer and Porter (1960), who found that C^{14} introduced in the upper leaves was readily translocated to the grain, but that little C^{14} introduced in the lower leaves was translocated to the grain. In these studies the labeled atoms were introduced by placing the leaves in vials of $C^{14}O_2$.

Relationship to Photoperiodism and Vernalization

Photoperiodic requirements for many grasses have been worked out (Hiesey 1957), and vernalization requirements for winter annuals have long been known; floral induction, however, of range plants other than grasses by photoperiod or vernalization has not been determined. Work in crop plants shows that photoperiod and vernalization requirements are common, and it is probable that such requirements exist in perennial range forbs and shrubs.

The floral stimulus in photoperiodically sensitive plants is received by the leaves and translocated to the buds (Salisbury 1961; Doorenbos and Wellensiek 1959). Cutting the leaves prohibits flowering, and apparently the inhibition is not related to food storage. In vernalization, it is most likely that the flowering part itself must be vernalized.

In assessing the effects of grazing on forage plants one should consider that defoliation may prevent shoot elongation by interrupting the photoperiodic response. This would reduce yields without producing a damaging effect on plant vigor.

EFFECT OF HERBAGE REMOVAL ON ROOT GROWTH AND ROOT WEIGHTS

Dozens of investigators working with shrubs, trees, and herbaceous plants have shown that defoliation or pruning reduces root growth (Curtis and Clark 1950). While yield of aboveground parts after clipping is somewhat erratic, root production is universally depressed.

Troughton (1957) pointed out that the loss of weight of existing roots and other underground organs after defoliation is relatively small; the main effect is retardation of new growth.

Crider (1955) found that root growth stopped within 24 hours after 50 percent or more of the foliage volume was removed. In all species studied, Crider found that single clipping which removed 40 percent or less of the foliage volume did not stop root growth. Crider used a glass-faced planter box to follow root growth in his studies, and he determined foliage volume by measuring the volume of water displaced by the foliage.

A modified version of the glass-faced planter box has been described in detail by Lavin (1961). If plants are grown in pots, roots existing at the time of treatment can be colored with carbon black so that they can be distinguished from new

[3] De Bano, Leonard Francis. The effect of season and degree of use on the physiological response and nutritive content of desert forage plants. (Unpublished master's thesis on file at Utah State Univ., Logan, Utah.) 1957.

roots (Crider 1955; Torres Mas [4]). The planter box, however, seems to have a greater variety of applications than the carbon black technique.

Oswalt et al. (1959) found that defoliation stopped root growth within 24 hours. Phosphorus 32 injected into the soil at different depths was not taken up until the new roots, originating from the basal leaf nodes, reached the P^{32} zone. Parker and Sampson (1930) found that roots of *Stipa* and *Bromus* did not develop root hairs when the plants were defoliated. This could explain the lack of nutrient uptake following defoliation.

The effect of clipping is about the same for rhizomes as for roots (Troughton 1957). Rhizome growth in *Agropyron repens* ceases when the shoots become senescent (Palmer 1958), so prevention of senescence by removal of terminal buds may promote rhizome growth.

Tesar and Ahlgren (1950) found that close, frequent defoliation of ladino clover reduced the weight of live stolons, but information is lacking about the effect of moderate clipping treatments on stolons.

RELATIONSHIP OF SEASON AND FRUITING TO CARBOHYDRATE STORAGE

Trends in Herbaceous Plants

In perennial herbaceous plants there is universally a decline in stored carbohydrates with the onset of spring growth. This period of decline generally lasts for a few weeks and is followed by a period of increasing carbohydrate accumulations. The spring decline has been well reviewed by Wilson (1944), Weinmann (1948, 1961), and Brown (1954).

Although the spring decline in carbohydrates is general, the pattern through the rest of the season is quite variable. One pattern is the recovery of carbohydrate storage after the initial spring loss with continuing increases in carbohydrate storage to the end of the season. Weinmann in his recent review (1961) concluded that a rise in carbohydrates with maturation was the most common pattern.

In a similar pattern there may be a midseason rise followed by a decline in carbohydrate storage in the fall. An example of the fall decline was reported by McIlvanie (1942) in his studies of bluebunch wheatgrass (*Agropyron spicatum*). Some decline of carbohydrates through the dormant season must occur as respiration continues and photosynthesis ceases.

[4] Torres Mas, Joaquin. The effect of gibberellic acid on root growth stoppage in several grasses following severe clipping. (Unpublished master's thesis on file at A. and M. College of Texas, College Sta., Texas.) 1958.

Although most of the reports on carbohydrate trends show a recovery of accumulations rather early in the season, a continued decline until midseason is also common. When the low point of carbohydrate accumulation is delayed in this fashion, the minimum generally coincides with budding, flowering, or fruiting.

A recovery in carbohydrates may take place from the spring decline followed by a secondary low at fruit set (Hyder and Sneva 1959; Mooney and Billings 1960). Wilson (1944) and Brown (1954) concluded that a low point in carbohydrates at the time of budding or flowering is the usual pattern, but the literature reviewed for this paper shows that such a correlation is by no means universal. In fact, Dils (1956) reported an increase in carbohydrates of roots and stem bases of *Lolium perenne* at the time of flowering, and Hirst et al. (1959) reported the same pattern in carbohydrates of the aboveground parts of alfalfa. McIlvanie (1942) reported that the high point of carbohydrate accumulation in bluebunch wheatgrass occurred during the time of seed maturation.

By far the most important mechanism causing midseason depression of yield and carbohydrate accumulations is fruit development. The earlier concept of the effect of fruiting was that fruits monopolized the carboyhdrates to the detriment of carbohydrate accumulation in the roots (Grandfield 1930; Curtis and Clark 1950).

The "monopolization" hypothesis is based on correlation only, and more evidence exists to contradict this hypothesis than to support it. For example, Blaisdell et al. (1952) found no apparent relationship between chemical composition and flowering in studies of bluebunch wheatgrass and arrowleaf balsamroot (*Balsamorhiza sagittata*). Hyder and Sneva (1959) found that deheading crested wheatgrass plants had no effect on carbohydrate content; carbohydrates diminished in both deheaded plants and intact plants at the time intact plants were flowering. Jameson and Huss (1959) found that removal of flowering stems of little bluestem had no influence on carbohydrate concentration of the roots but did reduce root weight.

Thus minima or maxima in carbohydrate storage have been associated with midsummer, flower stalk formation, flowering, and seed maturation, and the results have been so variable that no generalizations are possible at this time. It seems that continued investigations that include only carbohydrate determinations through the season will shed little light on the subject. The results may also be misleading since considerable variations have been noted even for similar situations.

A careful study of temperature and fruit effects should be included in any experiment on

seasonal trends in carbohydrates, and examination of hormone movements may be even more rewarding.

From the evidence available it is obvious that fruiting generally does induce some degree of senescence in plants. A recent study of *Pisum sativum* by Lockhart and Gottschall (1961) summarizes the present knowledge of fruit-induced senescence. In their study, sucrose sprays were ineffective in delaying senescence, which points out that carbohydrates by themselves are not responsible for senescence. Removal of fruits did delay senescence, however.

Trends in Woody Plants

Carbohydrate trends in woody plants have been reviewed by Kramer and Kozlowski (1960), who report "total carbohydrate content reaches a maximum in the autumn about the time of leaf fall, begins to decrease in late winter, and decreases rapidly in early spring when food is being used for growth of new twigs and leaves."

EFFECTS OF HERBAGE REMOVAL ON CHEMICAL RELATIONSHIPS OF ROOTS

Most studies of the effect of clipping on chemical components of roots have included only carbohydrates, although a few have considered nitrogeneous substances.

The common method of carbohydrate analysis follows the general method for reducing sugars with Fehling's solution as outlined by Wildman and Hansen (1940). All carbohydrate fractions are determined as reducing sugars, and the specific sugars are not determined. Little information is obtained about the structure of the polysaccharides. This procedure has the advantages of relative simplicity and easy availability of the necessary equipment. If the taka-diastase digestion and acid hydrolysis are done on the entire sample, one reducing sugar determination will give a figure for total carbohydrates (Weinmann 1947).

The reducing sugars are often expressed as glucose, but may be either glucose or fructose. Crockett[5] used a chromatographic technique outlined by Block et al. (1958) and determined that fructose and glucose were present in nearly equal proportions in big bluestem (*Andropogon gerardi*), side-oats grama (*Bouteloua curtipendula*), and blue grama (*B. gracilis*). The sample preparation was essentially the same as outlined above for the Wildman and Hansen method, but the determination was chromatographic rather than by Fehling's solution.

Disaccharides are generally expressed as sucrose, and there are usually no significant amounts of other disaccharides that need to be considered. Polysaccharides are often expressed as starch, however, and fructose polysaccharides are apparently as common as glucose polysaccharides. Although Weinmann (1948) reported that South African grasses did not contain appreciable amounts of fructosans, Norman (1939) found that the chief polysaccharide in grasses he examined was a fructosan. Fructosans are generally water soluble, and it is likely that they are usually reported as sucrose. By using chromatographic techniques Crockett (1960) determined that starch and fructosans were equally important in big bluestem, side-oats grama, and blue grama.

The hemicellulose fraction does not fluctuate so much as more soluble carbohydrates, and is usually considered to be more a structural material than a respiratory substrate (McCarty 1938; Weaver 1946). Whistler and Young (1960) found that C^{14} that accumulated in hemicelluloses of oat plants after injections of $C^{14}O_2$ did not move out of the hemicelluloses when the $C^{14}O_2$ was withdrawn. They concluded that hemicelluloses are stable end products and not part of a dynamic system. Priestly (1960), however, found that hemicelluloses in apple trees fluctuated much the same as sugars and starch. The role of hemicelluloses in woody plants may well be different than in grasses.

The effect of clipping on carbohydrates accumulations in the plant has been well reviewed by Weinmann (1948, 1961), Troughton (1957), and May (1960). Carbohydrates in roots generally decline for several days after defoliation, then begin to recover after a period of 1 to 3 weeks. The effect of defoliation varies with the intensity of treatment. The more herbage that is removed, and the more frequently it is removed, the more drastic the effect. McCarty (1935) presented data that show that depletion of carbohydrates is inversely related to the concentration of carbohydrates at the time of cutting. This relation is supported by later work of Sprague and Sullivan (1950) and Moran et al. (1953). Wilson (1944) in his review concluded that cutting when percents of carbohydrate were low was more effective in weed control than cutting when carbohyrates were high, but the studies cited above do not seem to support his conclusion.

The general hypothesis has been that carbohydrate accumulations are related to rate of plant regrowth and seed production. Some carbohydrates are needed by the plant as a respiratory substrate during the dormant season and also during the formation of new leaves in the spring or immediately after defoliation. May (1960)

[5] Crockett, J. J. Effects of intensity of clipping on three range grasses from grazed and ungrazed areas in west-central Kansas. (Unpublished master's thesis on file at Fort Hays Kansas State College, Hays, Kans.) 1960.

pointed out, however, that there is no evidence that additional carbohydrates are beneficial once these basic requirements have been met.

Several studies have shown that carbohydrates were directly related to clipping treatments or regrowth, and other studies have shown that they were not. Graffis (1961) did some comprehensive work with alfalfa that might help to explain some of the apparently conflicting results of other investigators. He found that regrowth could not be predicted from any single fraction of root carbohydrates at the time of clipping, but could be predicted from total carbohydrates. Regrowth was, in fact, inversely related to sugar content of the roots. The relationship of total carbohydrates with regrowth was parabolic; the maximum regrowth occurred when total carbohydrates in the root were 30 percent of the root weight, but regrowth was less with higher concentrations. This suggests that high levels of carbohydrates occur when some mechanism is operating that prevents utilization of these carbohydrates. It also supports May's (1960) conclusion that high levels of carbohydrates are not more desirable than more modest levels.

Some of the variations in carbohydrate determinations may be the result of temperature differences at the time of sampling. Kendall (1958) found that clipping reduced total carbohydrates from 90 mg./g. to 70 mg./g. on 75° F. days but to about 40 mg./g. on 95° days. In addition Wylam (1953) pointed out that there is a rapid hydrolysis of sucrose and fructosans after plants are harvested, and this may cause some variation in results due to temperatures. Postharvest breakdown could be avoided by freezing or heat killing the plant material immediately after it is harvested. Changes in soil-moisture stress may also cause differences in carbohydrates (Woodhams and Kozlowski 1954), and these differences might be confused with other seasonal effects.

Apparently leaves are required if root growth is to progress. The effect of cutting on roots is usually discussed in terms of carbohydrates. It is entirely possible, however, that other materials needed for root growth are more critical. Root cultures of many plants can be maintained in media consisting of mineral salts, carbohydrates, and vitamins (Tulecke 1961). Both liquid media and media solidified with agar have been used with success.

Thiamin, which is produced in the leaves, apparently is required by all roots. In addition pyridoxine, niacin, and nicotinic acid are required by various plants. Sucrose in about 2-percent solution is the usual carbohydrate added to the media.

Although grass root growth may be promoted by thiamin, niacin, and pyridoxine (Almestrand 1950b), continuous cultures have not been sustained with such simple media. Rye roots can be continuously cultured with mineral salts, carbohydrates, and yeast extract, such as Difco or Cenovis (Almestrand 1957). Difco extract is the easier of the two to obtain. Yeast extracts are used in concentrations of 0.0025 percent (Street 1957) to 0.5 percent (Straus and LaRue 1954). Much, but not all, of the yeast effect can be attributed to tryptophan (Roberts and Street 1955). The yeast extracts also contain several amino acids that promote growth.

Some sort of sterilization is necessary to prevent mold formation in the cultures, and yeast sterilized by bacteria-proof sintered glass filters (Seitz filters) is somewhat better than yeast sterilized by autoclaving (Tamaoki and Ullstrup 1958). Even with yeast, barley, wheat, and oats have not been continuously cultured. Extracts of higher plants have no effect on roots of barley and oats (Almestrand 1950a), but are effective in promoting growth of intact *Pisum* roots (White 1961).

Usually the pH of the culture media is controlled or adjusted. This may be done with HCl or KOH to arrive at a pH of 4.5 to 6.3 (Straus and LaRue 1954). A recent innovation in this field is the use of Amberlite IRC–50 exchange resin as a buffer to keep the pH between 4.2 and 4.5 (Hageman et al. 1961).

By using artificial media containing minerals, carbohydrates, vitamins, and other constituents in various combinations, it should be possible to determine what substances produced by the leaves are most critical for root growth after defoliation. At the time the literature review for this paper was completed, however, such a study had not been reported.

Instead of adding the organic constituents of the media to the minerals, Brown and Gifford (1958) mixed the organic constituents with agar and imbedded cotyledons of pine (*Pinus lambertiana*) in this agar medium. The embryo was then returned to the upright position, and the roots were imbedded in an agar-mineral mixture. This is a close approximation of the natural situation, and Brown and Gifford reported better growth than when the organic constituents were added to the root medium.

CONCLUSIONS

1. Effects of herbage removal by grazing are similar to effects of clipping only when the amount and kind of herbage removed are the same.

2. Removal of a major part of the herbage will reduce dry-matter yield unless (a) the clipped plants are present in a mixture and clipping

shifts the species composition to a more productive mixture, or (b) the site is occupied to a greater than optimum level and clipping reduces occupancy to a more favorable level, or (c) the site is not completely occupied and clipping stimulates vegetative reproduction. However, a temporary increase in dry-matter yield for 1 to 3 years may be followed by a reduction in yield. The detrimental effect of clipping increases when frequency or degree of clipping is increased.

3. Legumes appear to be more resistant to cutting treatments than many grasses. Shrubs appear to be resistant to grazing when utilization is expressed in terms of current annual growth, but these plants might appear to be less resistant if utilization were expressed in terms of photosynthetic tissue removed.

4. For clipping to stimulate tillering, the growing point or rapidly elongating leaves must be removed. Removal of leaves alone may inhibit sprouting in species that exhibit apical dominance.

5. Plant size and form may be changed under grazing as a result of selection of smaller or more prostrate genotypes within a species.

6. Protein content of forage species declines with maturity, and this decline can be lessened or prevented by cutting treatments. With clipping treatments that are not excessive, total protein yield is generally greater on clipped plots than on unclipped plots.

7. Seed yield is reduced by clipping and grazing. The processes involved may be (a) removal of the floral primordia, (b) removal of the flag leaf, awns, or upper leaves, which supply most of the photosynthetic material to the developing seeds, (c) interruption of the photoperiodic stimulus, which is received by the leaves, and (d) reduction of plant food reserves. Accumulated carbohydrates contribute only slightly to seed development.

8. Root weights and root growth are generally decreased by clipping. Clipping also reduces the amount of nutrients taken up by the roots.

9. In perennial plants carbohydrate accumulations decrease with the onset of spring growth. During the rest of the season, the carbohydrates of the underground parts of the plant may increase or decrease. The early spring decline is apparently due to utilization of carbohydrates in the production of the first few leaves. The mid-season decline, when it occurs, is apparently a temperature response or is due to fruit-induced senescence. Only a small fraction of the mid-season decline can be attributed to translocation of carbohydrates to the fruits.

10. Harvesting treatments result in lowered amounts of carbohydrates in the underground parts of herbage plants, and some carbohydrate reserves are needed for production of new leaves after defoliation. Once the carbohydrate needs for new leaf tissue have been met, there is little reason to believe that additional carbohydrates are beneficial to the plant. Some storage products, including carbohydrates and proteins, may be associated with ability of the plant to survive freezing and other adverse conditions.

11. Although the deleterious effect of defoliation on root growth of plants is generally considered to be due to reduced carbohydrates available to the roots, other substances produced by the leaves and necessary for root growth, such as thiamin and other vitamins, may be involved. The importance of vitamins in relation to defoliation has not been investigated.

12. Adequate techniques are available for study of the grazing effect on individual plants, but more attention should be paid to environmental control, distinguishing between plant parts, and proper interpretation of the physiological processes involved.

EFFECTS OF TRAMPLING ON SOIL AND VEGETATION

Hudson G. Reynolds and Paul E. Packer

Range management is concerned primarily with production of nutritious and high-yielding forage plants for utilization by livestock and game animals in keeping with maintenance of the soil resource. Soil stability depends largely upon proper disposition of precipitation by vegetation and soil mantle. Excessive trampling can reduce soil stability by disrupting this important function of soils and plants.

Trampling by livestock and big game beyond proper limits increases overland flow and accelerates soil erosion. Effective management of many rangelands will require additional quantitative criteria as to tolerable limits of grazing use and trampling disturbance for resource maintenance. Development of these criteria will require critical measurement and proper interpretation of the complex interrelations among climate, vegetation, soil, water, and animals.

This paper evaluates present knowledge of the effects of trampling upon soil and vegetation by: (1) examining briefly some fundamental con-

cepts regarding plant-soil-water-animal relations; (2) considering some effects of compaction on soils and plant growth; (3) presenting some results of measurements of livestock and game trampling on soil and vegetation; and (4) describing some current techniques for measuring soil compaction. Several recommendations are offered for advancing knowledge about trampling influences to improve management of rangelands for livestock grazing, game habitat, and other products.

SOIL INTERRELATIONS

Many environmental factors are involved in soil formation, including topography, parent material, climate, plants and animals, and time (Jenny 1941). Each of these soil-forming factors may vary independently, and many combinations of factors are possible under natural conditions. Hence, in evaluating the effects of trampling upon soil and vegetation, conclusions must be referred to a specific combination of environmental factors. Moreover, since soil formation is dynamic (Kellogg 1934), evaluations can be expected to be different, not only from place to place, but for different intervals of time for the same place.

SOIL COMPACTION

Effects on Soil Properties

Structure is the property of soils most readily altered by compaction. Soil structure determines moisture relations and aeration of a soil. Also, such properties as pore volume, air capacity, and permeability depend in part upon structure. Compaction affects these soil properties, and reduces the effectiveness of soil for promoting growth of vegetation (Lutz and Chandler 1946). Pore volume of soils determines the space available for air and water. The size and relative proportions of pores affect water-holding capacity, aeration, and percolation. Compaction lowers pore volume.

The effects of compaction upon soil structure and porosity are most commonly measured in terms of bulk density, pore-size distribution, and infiltration capacity. Bulk density of a soil refers to the mass of ovendry solids per unit volume. The proportion of soil volume unoccupied by ovendry solids is a measure of total porosity. For the same texture of soil, low bulk densities are associated with relatively porous conditions; high densities with compaction.

Pore-size distribution is the fraction of the total soil volume occupied by pores of a given diameter. A common division of size is between capillary and noncapillary pores. Pore size largely determines permeability and retention of water.

Infiltration capacity is defined as the volume of ponded water in an infinitely thin layer of unit area that passes into the soil per unit of time. Infiltration is usually expressed as centimeters or inches of absorption per hour (ASAE/SSSA 1958). Physically, infiltration capacity reflects surface conditions, internal geometry of pores, and moisture content of the soil.

Effects on Growth of Vegetation

Root development.—The effect of soil compaction upon root development has been related to bulk density. Sunflower roots did not penetrate soils that were compacted to bulk densities from 1.46 to 1.63 in clays and in excess of 1.75 in sands (Veihmeyer and Hendrickson 1948). Penetration of sugar beet roots ceased at a bulk density of about 1.9, and feeder root development was restricted at 1.8; root penetration and distribution were uninhibited at 1.5 (Pendleton 1950).

Critical bulk densities for root growth vary among species. Root growth of western redcedar was satisfactory on soils with a bulk density as high as 1.80, while growth of red alder roots ceased at a density of 1.50; root growth of Douglas-fir and western hemlock was not affected until bulk densities reached 1.25 (Forristall and Gessel 1955).

In terms of soil porosity, root development of sugar beets was restricted at noncapillary porosities of 3.5 percent in sandy loam and 11.7 percent in silt loam. At porosities of 14 and 18 percent, in these same soils respectively, root development was unrestricted (Pendleton 1950). Mustard roots were not found in clods of soil with pore space below 38.7 percent, whereas wheat roots were present in clods containing only 30 percent pore space (Fountaine and Payne 1952).

Top growth.—The result of soil compaction is reflected as reduced top growth of plants. In woodlands of North Carolina, heavy compaction of the upper 6 inches of soil reduced growth of yellow-poplar by 50 percent, hickory by 30 percent, and red maple by 27 percent (Johnson 1952). Heavy soil compaction has also been observed to reduce growth of mustard (Fountaine and Payne 1952), yields of sugar maple (Dambach 1944), and production of ryegrass-white clover associations (Edmond 1958), and alfalfa-brome mixtures (Tanner and Mamaril 1959).

Beneficial effects.—Controlled soil compaction benefits some soils. For example, growth and development of cotton were better on compacted soil than on uncompacted soil (Heath 1937). Better growth on compacted soil was attributed

to more plant nutrients and moisture per unit volume of soil. Thus on some soils, where moisture is limiting and aeration adequate, light compaction may be beneficial.

TRAMPLING EFFECTS ON RANGELANDS

Soil compaction from trampling by livestock and big game may detrimentally influence both soils and plants. Potential pressures for compaction by livestock are high. An ordinary farm horse may exert trampling pressures as high as 29 to 57 pounds per square inch (Blair 1937). Static load pressures for cattle have been calculated at about 24 pounds per square inch, and for sheep at about 9 pounds per square inch (Lull 1959). Thomas (1960) considers heavy trampling effects equal to, if not more important than, excessive grazing in reducing forage production.

Several investigators have measured the effect of trampling by grazing animals upon rangeland vegetation and soils. Vegetation effects have been concerned mostly with dead vegetation (litter and mulch); soil effects with properties of bulk density, porosity, and infiltration.

Effects on Vegetation

Most studies of rangeland trampling have not separated the direct influences of destruction of tops, litter, and mulch from indirect effects of soil modification upon growth of vegetation. Neither have the effects of trampling been separated from those of grazing. The effects of grazing and trampling are thus confounded in most studies.

Unconfounded effects.—The unconfounded effects of "artificial trampling" on ground cover were studied by applying a 0.2-square-foot steel "hoof," attached to the end of a weighted bar, to different kinds of vegetation (Packer 1953). By means of controlled space and number of impacts, trampling effects were varied and expressed as a percent of total disturbance. On both wheatgrass and cheatgrass vegetation, artificial trampling at any level up to 40 percent reduced amount of ground cover and increased size of bare soil openings. Above this level, effects were constant. With ground cover of 90 to 95 percent, none of the trampling treatments reduced ground cover to less than 70 percent (an acceptable level for the site), nor increased bare soil openings beyond maximum acceptable distances for the site (more than 4 inches on wheatgrass sites or more than 2 inches on cheatgrass sites). With 80- to 85-percent ground cover, trampling disturbance of 40 percent or more reduced ground cover and increased bare spaces beyond acceptable levels for the site. At 70- to 75-percent ground cover, all but the 10-percent trampling disturbance altered ground cover and bare opening conditions beyond acceptable levels for the site.

Confounded effects.—In the following examples from the Great Plains, effects of trampling upon surface litter and mulch are confounded with effects of forage removal by grazing. Near Miles City, Mont., Reed and Peterson (1961) sampled rangelands subjected to light, moderate, and heavy grazing. They found that litter accumulation between grass clumps was approximately 2 to 2.5 times greater under the lightest than under the heaviest grazing.

Branson and Weaver (1953) related mulch to range condition of grasslands of the northern Great Plains. Mulch was defined as: ". . . . the undecayed and partially decayed plant material that was recovered from the soil surface without removing mineral constituents or living plant materials." Three topographic sites were sampled—lowland sites, presumably with highest available moisture; hillside sites, with intermediate moisture; and hilltop sites, with least moisture. Quantities of mulch recovered are shown in the following tabulation.

Condition class	*Lowland (pounds per acre)*	*Hillside (pounds per acre)*	*Hilltop (pounds per acre)*
Excellent	8, 540	5, 900	3, 980
Good	3, 883	3, 740	2, 980
Fair	1, 300	1, 710	1, 132
Poor	634	281	281

On all three topographic sites, the most mulch was measured on range in excellent condition, the least on poor range. With minor exceptions in the poorer condition classes, amount of mulch decreased with reduction in available soil moisture from lowland to hillside to hilltop sites.

Hopkins (1954) measured the amount of mulch associated with grazed and ungrazed conditions on several different sites. His results are given in the tabulation following.

Site and vegetation	*Grazed (pounds per acre)*	*Ungrazed (pounds per acre)*
Upland, shortgrass	1, 680	4, 780
Lowland, wheatgrass	1, 740	3, 960
Hillside:		
Big bluestem	900	9, 060
Western wheatgrass	2, 380	6, 870
Sand dropseed	1, 400	3, 600
Buffalograss	1, 280	2, 290

Again, grazed sites had consistently less mulch. Also, on hillside sites, as range varied from the better condition of big bluestem to the poorest condition of buffalograss, ungrazed sites gradually lost litter.

Packer [1] measured the impact of heavy trampling and grazing by elk on herbaceous vegetation of the Gallatin winter range in Montana. Here, ground cover (plant basal area and litter) averaged 30 percent on currently grazed sites, 47 percent on formerly grazed but now protected sites, and 96 percent on virtually pristine sites that probably had seldom, if ever, been grazed.

Effect on Soil Characteristics

Bulk density.—Alderfer and Robinson (1947) measured bulk densities in the 1-inch surface layer on a variety of pasture sites on clay loams and sandy loams in Pennsylvania. Densities ranged from 1.54 to 1.91 for heavily grazed sites and from 1.09 to 1.51 for ungrazed and lightly grazed sites. In second-growth hardwood stands of central New York, Chandler (1940) found that bulk density of loams and silt loams was 1.15 on heavily grazed sites, and 0.92 for ungrazed sites. On Allegheny River watersheds, Trimble et al. (1951) determined average bulk densities of the A_1 horizon to be 0.92 for grazed and 0.51 for ungrazed woodlands. In the lower A horizon, bulk densities were 1.07 and 1.01, respectively.

In three South Dakota shelterbelts of silty clay loam texture, bulk densities averaged 1.22 under heavy grazing as against 1.01 for protected areas (Read 1957). In the Lake States, Stoeckeler (1959) determined that bulk density of the surface 3 inches of soil in oak woods was 1.15 for grazed and 0.89 for ungrazed conditions. Kucera (1958) also found bulk densities higher under grazed conditions. On southerly exposures of the Gallatin elk winter range currently being grazed, Packer [1] found that bulk density of the surface 2 inches of soil averaged 1.29. On similar sites formerly grazed but now protected, bulk density was 1.17; on virtually ungrazed sites it averaged 0.71.

Bulk densities increase with heavier intensities of grazing. Reed and Peterson (1961) sampled areas subjected to heavy, moderate, and light grazing on the northern Great Plains. They found that compaction was consistently highest where grazing was heaviest.

Soil effects, as measured by bulk densities, are related to other soil characteristics. As bulk density increases, organic matter is lowered (Chandler 1940). Soils with large clay fractions are most easily compacted, and wet plastic soils are most easily damaged (Tanner and Mamaril 1959).

[1] Packer, P. E. Watershed protection requirements for the Gallatin elk winter range. (Unpublished manuscript, U.S. Forest Serv. Intermountain Forest & Range Expt. Sta.) 1961.

Porosity.—On a variety of pasture sites on clay loams and sandy loams in Pennsylvania, noncapillary porosity for grazed sites ranged from 3 to 10 percent; for ungrazed sites the range was from 15 to 33 percent (Alderfer and Robinson 1947). In the Alleghenies, noncapillary porosities were 12.6 percent in the A_1 horizon under moderate grazing of woodlands as compared to 23.4 percent for no grazing. In the lower A horizon, noncapillary porosities were 13.7 and 14.8 percent, respectively (Trimble et al. 1951).

In southern Wisconsin, Steinbrenner (1951a) compared six ungrazed and grazed woodlands, and found that macroscopic pore space was 15.5 to 37.0 percent for ungrazed areas, and 12.5 to 18.0 percent for grazed areas. In three South Dakota shelterbelts, large pore space was found to be 7.6 percent under grazing as against 14.1 percent for no grazing (Read 1957). Kucera (1958) found the greatest difference in capillary porosity on grazed areas to be associated with the surface inch of soil. Below that level he could distinguish no difference. Reed and Peterson (1961) found a reduction in large noncapillary pores associated with grazing that ranged from 1.5 to 6.8 percent.

Infiltration.—In addition to loss of air space and moisture-holding capacity, reduction in large noncapillary pores results in poorer infiltration. Johnson (1952) found that grazing reduced infiltration 91 percent in the cove-hardwoods type and 67 percent in the oak-hickory type of North Carolina. Alderfer and Merkle (1941), working on Hagerstown silty loam in Pennsylvania, measured percolation rates of 18 cc. per minute for unpastured bluegrass, as compared to 5.5 cc. per minute for pastured bluegrass. Peele (1955) found infiltration rates for grazed wet soil to be 0.40 inch per hour after 1 hour of simulated rainfall; for ungrazed wet soil, infiltration rate was 2.12 inches after 2 hours of testing.

Steinbrenner (1951) found permeability of the 2-inch soil level in ungrazed woods in Wisconsin to be 3 to 245 times greater than that of grazed woods. On Allegheny watersheds, Trimble et al. (1951) measured an average percolation rate of 30.2 inches per hour through the A_1 horizon in grazed pastures as compared to 132.0 inches per hour in ungrazed pastures. Stoeckeler (1959) compared infiltration rates of grazed and ungrazed native oak woods and mature Scotch pine plantations in Wisconsin, and found a 93-percent reduction in water intake associated with livestock trampling.

Hopkins (1954) compared water absorption of grazed and ungrazed sites on shortgrass and wheatgrass rangelands with a ring-type infiltrometer. Water was absorbed much faster on ungrazed than on grazed sites, and the difference

increased with time. Also, infiltration was 183 percent greater on mulched than on denuded plots at the end of a 2-hour period. The difference in infiltration between ungrazed and grazed areas was greater than between mulched and unmulched, which indicates the mulch only partially controls infiltration. One-half inch of mulch reduced evaporation 41 percent over bare soil during the first week as compared with a reduction of 67 percent for 3 inches of mulch.

Reed and Peterson (1961) found that, on both sandy loam and clay soils, grazing reduced infiltration rates by about one-half. Even the lightest intensity of grazing lowered rate of infiltration. For rainfall conditions that prevailed, depth of wetting under the heaviest level of grazing was reduced about 8 percent in sandy soils and 20 percent in clays.

Packer (1953) measured a close reciprocal of infiltration—overland flow—on artificially trampled wheatgrass and cheatgrass ranges in Idaho. Under both types of vegetation, where the ground cover was 90 to 95 percent, none of the trampling treatments increased overland flow significantly. At 80- to 85-percent of ground cover, 20-percent trampling disturbance did not increase overland flow, but 40- and 60-percent disturbances did. Under 70- to 75-percent ground cover, all but a 10-percent trampling disturbance increased overland flow significantly.

Organic matter.—Because of less production, redistribution, and destruction of litter, soil organic matter is usually reduced by grazing. Reed and Peterson (1961) measured small but consistent differences in organic matter between heaviest and lightest intensities of grazing. Kucera (1958) found small differences in organic matter between grazed and ungrazed prairie to a depth of 4 inches. Lodge (1954) found organic matter slightly higher on ungrazed than on grazed sites.

Other effects.—On four mixed prairie sites, on loam and silt loams, significant differences were detected in moisture content and phosphorus between grazed and ungrazed sites. Moisture values were lower on grazed sites. Phosphorus values were higher for the 0- to 4-inch horizon on grazed sites; when moisture increased, however, phosphorus values were lowered (Lodge 1954).

Moisture content of soils at the time of trampling influences compaction. Maximum compaction is attained at a moisture content about midway between wilting point and field capacity (Lull 1959).

Depth of effect.—Alderfer and Robinson (1947) found that trampling effects were confined mostly to the 1-inch surface layer. In the 1- to 3-inch and the 3- to 6-inch layers, intensity of grazing did not affect bulk density. In a later study, however, Robinson and Alderfer (1952) found that the 0- to 1-inch depth was not compacted, whereas the 1- to 5-inch layer was compacted. Keen and Casheen (1932) used a penetration rod to measure compaction by sheep on light, sandy soils to a depth of 10 cm. Compaction was greatest in the 3- to 4-centimeter layer. Kucera (1958) found greatest differences in bulk density in the surface inch, with no apparent difference below 4 inches. In general, soil layers above 6 inches are most affected (Tanner and Mamaril 1959).

Recovery of Soil From Trampling

Recovery of soil from trampling disturbances has not been intensively studied. Measurements of recovery of Kentucky bluegrass meadows along stream bottoms in the Black Hills suggest some of the possibilities in this regard (Orr 1960). Soil properties were measured inside and outside of livestock exclosures constructed between 1940 and 1955 at four sites on medium-textured soil of alluvial origin. Measured were bulk density, total pore space, and small and large capillary pore space.

At three of the four sites, bulk density of the 0- to 2-inch soil layer was significantly higher outside the exclosures. At only two sites was bulk density of the 2- to 4-inch layer significantly higher outside; below 4 inches no significant differences were measured except for the 8- to 10-inch layer at one site.

Volume of large pore space (drained by 60-centimeter water tension) in the 0- to 2-inch and 2- to 4-inch soil layers was greater inside the exclosures at all four sites. Below 4 inches, differences in amounts of large pore space were not significant for 5 of the 16 comparisons. Reaction of small pore space to grazing was the opposite of large pore space.

There was evidence of recovery from compaction in both the 0- to 2-inch and 2- to 4-inch layers of the sites protected for 17 and 9 years as measured by bulk density and large pore space. At the site protected for 5 years, there was recovery in only the 0- to 2-inch layer; at the site protected for 7 years, the only evidence of recovery was in the volume of large pore space in the 0- to 2-inch layer.

Effective stabilization of soil during high-intensity summer rainstorms on the Gallatin elk winter range required at least 70 percent ground cover and bulk densities of no more than 1.04 in the surface 2 inches of soil.[1] After 4 years, these requirements were attained on two sites: (1) those that had been both protected from elk use and reseeded, and (2) virtually ungrazed sites that were protected by snowdrifts all winter and during early spring grazing. Protected native

cover sites showed considerable improvement in both ground cover and bulk density conditions, but were below minimum protection requirements. Unprotected sites in this particular study continued to remain far below desirable levels.

TECHNIQUES FOR MEASURING SOIL COMPACTION

Techniques for measuring soil compaction have a specialized literature and have been critically reviewed by soil specialists (ASAE/SSSA 1958). The attempt here is merely to identify some of the widely accepted techniques, and to cite an authority for each method.

The measurements that have greatest promise for determining the effects of trampling on rangelands include (1) bulk density and total porosity, (2) pore space, and (3) infiltration rate. Other refined techniques, which might be adopted for intensive studies, include mechanical strength, particle displacement, and hydraulic conductivity (ASAE/SSSA 1958).

Bulk Density and Total Porosity

Bulk density and its computed companion, total porosity, are generally measured by core samples, by the volumeter, or by the neutron method.

Core samples.—Cylindrical cores are obtained with handtools or power-driven equipment. Bulk density is obtained by determining the ovendry weight of a known volume of soil. Porosity can be computed by measuring or assuming a density of the solids (Lutz 1947).

Volumeter method.—A small balloon filled with water is connected in a closed system containing a mercury volumeter. The balloon is placed in an excavation in the soil, and water volume is adjusted to fit the hole. Bulk density of the soil is determined by dividing weight of the soil excavated by the weight of water required to fill the hole (ASAE/SSSA 1958).

Neutron method.—Several commercial instruments contain a radioactive source, the intensity of which varies with soil density at known distances from the source. Wet bulk density is obtained from radiation measurements and converted to a dry weight basis. In saturated soils, radiation intensity measures total porosity directly, if specific gravity of solids is known. When bulk density and specific gravity are known, moisture content of the soil can also be measured (van Bavel et al. 1956).

Pore Space

Measurements of pore space are based upon mathematical assumption of tensions associated with pore size. For tensions less than 100 millibars (mb.), tension values are determined by a porous supporting platform and computed from a tension table (Leamer and Lutz 1940). For tensions from 100 to 1,000 mb., pressures are applied in the gas rather than the liquid phase with a porous plate cell (Richards and Ogata 1956). For highest tensions, a pressure membrane apparatus is employed (Richards 1947).

Infiltration Rate

The rainfall simulator and the cylindrical infiltrometer are common methods for measuring infiltration. With the rainfall simulator, a small area is sprinkled at a known rate, and, by measuring overland flow, infiltration rate can be computed (Wilm 1941). The cylindrical infiltrometer method employs a small cylinder in which rate of absorption of given amounts of water are measured (Burgy and Luthin 1956).

GENERAL CONCLUSIONS

1. The role and importance of micro-organisms, plants, and animals on soil factors in primary and secondary successions of grasslands and shrublands need further study. Knowledge of these factors and processes is basic to proper management of the soil-plant-animal complex.

2. In general, soil compaction decreases penetration of water, reduces water-storage capacity, lowers aeration, inhibits root penetration, and restricts activities of soil animals. These effects are reflected in depressed top growth of many plants. The effect of soil compaction on range plants has not been adequately studied. More information for specific range plants and soils is needed to guide management decisions.

3. Trampling effects on range soils have been measured as increased bulk density and reduced total porosity, organic matter, and infiltration. These effects are most pronounced in the surface 6 inches of the soil mantle. Trampling effects are most severe for moderately wet soils and those with a high clay fraction. Compaction standards will be needed for most plant associations and soil series as range management practices become more intensive.

4. Measurements of the effect of trampling upon plant cover and litter are mostly confounded by grazing. Unconfounded studies show that plant cover and litter are reduced by trampling. Dissipation of litter decreases infiltration of precipitation and increases moisture losses from surface layers of the soil. Studies are needed that separate the effects of top removal and trampling upon top growth so that the relative im-

portance of trampling and grazing can be better understood.

5. More studies of soil recovery from trampling under different management systems are needed. An exemplary study is that of Kentucky bluegrass meadows in the Black Hills. Here, considerable recovery from trampling occurred within 5 years of livestock exclusion, and full recovery was reached within 5 to 9 years. Other soils, plant associations, and management practices can be expected to give different results.

6. Techniques seem to be adequate for measuring soil compaction. Moreover, technical groups interested in trafficability of soils are now improving measurement techniques. The main research lag is that of determining what effect compaction and trampling have upon reproduction, growth, and production of range vegetation.

COMMITTEE REPORT ON MEASUREMENT AND EVALUATION OF RANGE USE BY LIVESTOCK AND GAME

The problem of measuring and evaluating range use is one of determining the relation between animal use and (1) vegetation, (2) site, and (3) production of livestock, wildlife, timber, water, and other products of the land. Measurement of range use is necessary to both range management and wildlife habitat research to evaluate effects of grazing treatment. Treatment may beneficially or detrimentally influence the vegetation, site, or economic returns.

Numerous methods for determining utilization have been proposed or used. These methods express utilization either as amounts of plant materials removed or remaining. Refinement of utilization measurement techniques will require more attention to the removal of photosynthetic tissue and reproductive parts of plants.

Distinguishing between use by ruminants, rodents, and insects needs further attention. Combinations of plant use and animal signs offer the best current means for differentiating such use. More precise methods are needed for evaluating how different kinds of animals use the range.

Accuracy, precision, and efficiency of major methods in use need further evaluation. Attention should be given to new methodology and to reevaluation of our objectives for measuring utilization. This will lead to better interpretation of results in terms of plant-animal relationships.

The fecal count method is a useful tool. Its utility and accuracy for determining relative abundance and seasonal trends of animal populations depend upon adequate sampling, proper aging of feces, and correct application of the method during suitable seasons.

Burrow counts are useful for estimating low populations of pocket gophers and perhaps other rodents, but not for dense populations. Mound counts have utility in providing rough indices of relative populations and further study of this approach is needed.

Spot-count sampling is useful for determining relative numbers and trends in numbers of game birds. Night spotlight counting is also useful for determining relative numbers of nocturnal animals, including deer.

Plants react to grazing according to the kind and amount of plant tissue removed, but kind of tissue removed has too often been ignored. Dry matter and seed yields are generally reduced by tissue removal, except that dry matter yields may be increased when the stem apex is removed without a large reduction of photosynthetic material. Protein yields are generally increased by clipping or grazing, but measures of protein and other forage value have been omitted from most range plant clipping studies. Root growth is generally reduced by removal of photosynthetic tissue, and this response is one of the major effects of clipping. The chemistry of roots as influenced by herbage removal has not been investigated except for general carbohydrate analyses. Such analyses have given highly variable results.

The effects of trampling upon soils and vegetation have been inadequately evaluated. Trampling indirectly affects vegetation through soil compaction. Soil compaction decreases penetration of water, reduces water-holding capacity, lowers aeration, and restricts activity of soil flora and fauna. These soil modifications inhibit root penetration and reduce top growth. Trampling directly reduces living cover and litter, which in turn decrease infiltration and increase surface evaporation.

Although techniques for measuring soil compaction seem adequate, more trials under range situations are needed.

RECOMMENDATIONS

1. Evaluation of use by grazing or browsing animals should consider both the harmful and beneficial effects of grazing, trampling, and animal waste on the microenvironment, vegetation, and forage production.

2. The development of electronic instruments for herbage and browse utilization measurements shows promise and should be encouraged.

3. Results of previous utilization experience should be compiled and evaluated, and additional studies made as necessary to determine the statistical adequacy of methods now in use.

4. Additional research should be undertaken to make "sign" methods more useful and meaningful. Topics to investigate should include:

(a) Distribution of droppings in relation to habitat.
(b) Factors affecting defecation rates of major game species.
(c) Possible use of pellet weight as a measure of range use.
(d) Use of mounds, casts, and burrows to census rodents.

5. More attention should be given to the relation of herbage removal to the physiology of the plant including:

(a) Removal of specific plant parts.
(b) Yields of crude protein, T.D.N., or other suitable indices to animal production values.
(c) Influence of temperature, moisture, and phenology at time of clipping.
(d) Carbohydrate differentiation and production.
(e) Chemical interaction of plant parts as influenced by clippings.

6. Studies of trampling should be undertaken to determine:

(a) Amount, intensity, and distribution of trampling under range conditions.
(b) Processes contributing to soil deterioration and recovery.
(c) Soil and plant disturbance associated with kind, intensity, and class of grazing.
(d) Methods of promoting soil recovery.

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Design and Conduct of Grazing Experiments

LAYOUT OF EXPERIMENTAL UNITS

J. B. Hilmon, J. L. Clutter, and D. R. Cable

There is no ideal layout for a grazing experiment. Each installation reflects a unique combination of objectives—terrain, vegetation types, animal characteristics, grazing periods, etc., and the layout adopted must be adjusted to the individual situation.

Factors affecting layout of experimental units are in two broad groups: (1) The statistical and (2) the biological and physical. The statistical considerations are relatively clearcut; however, the biological and physical considerations in particular are extremely complex and erratic in the magnitude of their effects, depending on place and year. Moreover, most past work has not been summarized in sufficient detail to permit the extraction of pertinent planning factor information or the critical evaluation of the biological situation. This paper, then, will discuss some of these considerations in the layout of experimental units.

OBJECTIVES OF GRAZING EXPERIMENTS

The general purposes of typical grazing experiments are for the testing of hypotheses about, and the estimation of responses to, some well-defined grazing treatments. Objectives of grazing experiments include evaluation of the effects of grazing or browsing of range forage by livestock or big-game animals on (1) individual plant species, communities, or combinations thereof; (2) soils, erosion, and runoff; (3) the grazing animals; or (4) any combination of the first three items. In addition, grazing animals are used in experiments to evaluate the effectiveness of treatments, such as levels of fertilization and plant control, in terms of animal response. Responses to grazing treatments may be expressed through such diverse items as vegetation production, plant succession, animal production, market values, soil compaction, runoff, etc.

FACTORS AFFECTING LAYOUT OF GRAZING EXPERIMENTS

The adequacy and efficiency of the experiment in fulfilling these objectives will depend on a number of considerations. Some factors which may operate as conditions of the experiments or which may formally enter grazing experiments as variables are as follows:

1. Type of plant community—natural associations and their relation to condition classes; productivity in terms of average grazing capacity, and magnitude of variations as influenced by weather; and effect on the community of artificial improvement practices such as seeding, plant control, and fertilization.
2. Act of feeding or browsing—rate of stocking or percentage of utilization; period of grazing as related to length, season of year, or stage of plant growth; system of grazing (continuous, rotation, and rotation-deferred).
3. Grazing animal—type of livestock including sex, age, or breed of livestock; type of big game (deer, elk, or antelope) and their sex or age; and combination of livestock and game.
4. Number of years the experiment is to be continued.
5. Availability of water.
6. Physiographic factors—soils and topography.
7. Cost factors—fence, road, and other facility construction; maintaining and operating facilities; experimental animals; record collection.

Some of the primary statistical considerations follow:

1. The responses observed in the experiment should be representative of those obtainable by imposing the treatments on other areas in nonexperimental situations. Some conditions to be satisfied: (a) The experimental area should be typical of the population to which the research results are to be applied, (b) the animals involved should be representative of breed(s) and

classes generally used, (c) the climatic conditions existing during the study should not be unusual, and (d) the introduction of extraneous effects caused by abnormal animal behavior, imprecise response measurements, or insufficient definition or incorrect application of treatments should be avoided.

2. The experiment must provide an estimate of experimental error.

3. Estimates of the average responses obtainable by application of the various treatments should be made with the maximum precision consistent with time and cost. However, judgment should not be based on cost alone. A more appropriate concept of economy would be maximization of the amount of information gained per dollar expended. Application of this criterion to many existing experiments suggests that more, rather than less, effort should have been invested to achieve economy.

4. The experiment should provide adequate sensitivtiy. That is, the probability of detecting appreciable differences in treatment effects, if such differences are present, should be reasonably large. An experiment with only a 20-percent chance of detecting the expected treatment effects is not a sound research investment.

EXPERIMENTAL DESIGN CONSIDERATIONS

After the number and type of treatments have been selected for an experiment, several items must still be considered before field installation can be started:

1. A statistical design must be selected.
2. The size and shape of the experimental unit must be determined.
3. The number of replicates (number of experimental units receiving each treatment) must be specified.
4. Techniques must be specified for measuring or estimating the response to treatment on each experimental unit. In range grazing studies this will involve the development of sampling plans since complete measurement of experimental units usually is impossible.
5. Treatments must be assigned to the experimental units.

All of these considerations are closely interrelated. For example, the adequacy of a number of replicates will be influenced by the statistical design, the size and shape of the experimental units, and the fraction of the experimental unit sampled. Despite this interdependency, some individual consideration of each of the above items is desirable. It is important, however, for the researcher to note and evaluate the interrelationships in these items of experimental technique so that the final plan will reflect a balance of possible alternatives.

CHOICE OF STATISTICAL DESIGN

Most grazing studies have used completely randomized or randomized block designs. These two designs probably will remain the usual choices. Although most field researchers prefer randomized block designs because of their greater efficiency, completely randomized layouts are often justifiable. In cattle experiments, large pastures are often necessary. With large units, block size may be increased to the point that variability within blocks is as great as variability between blocks. When this situation occurs, no advantage can be gained by blocking the experimental units. When units can be blocked into reasonably homogeneous replicates, however, the researcher is well advised to install the experimental units in blocks.

SIZE AND SHAPE OF EXPERIMENTAL UNITS

The framing of specific recommendations concerning unit size in grazing experiments is virtually impossible because of the many aspects of these experiments that are related to unit size. In addition to the usual factors of statistical efficiency which influence field plot size, such items as provision of supplemental feed and water, fencing expenses, and regulation of grazing intensity must also be considered. The problem under consideration in unit size decisions is essentially the following: If each treatment in an experiment can be applied to x acres, should application be made to two experimental units of x/2 acres each, to three experimental units of x/3 acres each, etc. Kempthorne (1952) and Federer (1955) have shown that statistical efficiency increases with decreasing unit size. However, considerations other than statistical efficiency often are present in grazing studies, and these factors will generally limit minimization of unit size. Among these considerations are the following:

1. If tester animals are in the study, the unit must be large enough to support their nutritional needs and not alter their usual pattern of behavior. Biological factors operating include productivity of the range, extent of the range types, kind of grazing animal, and duration of grazing. In studies where animals are used only for imposing treatments and effects are measured in plant responses, smaller experimental units are often feasible.

2. For a constant experimental area, total cost of the experiment will increase with decreasing unit size. This added cost will result from such items as increased fencing, more watering facilities and feed bunkers, greater animal handling costs, etc.

The pattern or variability of the vegetation usually has not been considered in unit size determination. In studies where animal and range responses must be evaluated concurrently, data on range variability can be most helpful in designing the sampling scheme to obtain the most efficient measure of pasture production. When only the range response is desired, a study of vegetation pattern can determine the size of the experimental unit and the replications required. The results may often indicate a smaller unit than commonly thought efficient.

On the Caloosa Experimental Range in Charlotte County, Fla., for example, a sampling study was conducted to estimate the intrablock variation in weight of the major species (*Aristida stricta*) for various block sizes (fig. 1). To obtain this data, 40 acres of rangeland were divided into 1-acre units. Herbage production by major species or groups was estimated for each acre by a double sampling method on two random transects each consisting of five small plots. Random transects were drawn from block sizes of 1, 2, 5, 10, and 20 acres. Two transects per block were drawn for each of forty 1-acre blocks; 2 and 4 transects per block were drawn from each of twenty 2-acre blocks; and 2, 4, and 6 transects per block were drawn from each of the 5-, 10-, and 20-acre blocks. Where varying numbers of transects per block were drawn from a block size, weighted averages of variances were obtained.

A smooth curve for the average error variances per 9.6 square foot plot for the varying block sizes is plotted in figure 1. Although the treatments imposed in a study may change the pattern of variation from that present in preliminary sampling studies, such estimates are still quite useful in evaluating the effect of varying unit and block sizes.

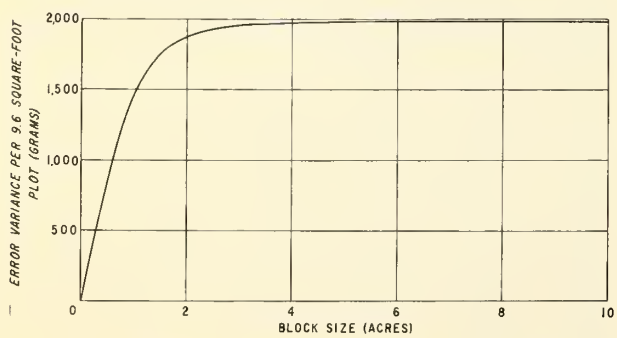

Figure 1.—The relation between error variance per 9.6-square-foot plot and block size for *Aristida stricta* on the Caloosa Experimental Range.

In summary, the unit size should be kept as small as biological and cost considerations permit. Kempthorne (1952) considers $\frac{1}{40}$-acre units to be reasonably satisfactory for pasture experiments with sheep but recommends unit sizes of 1 to 5 acres for cattle. In studies evaluating the effects of grazing by livestock and big game, two units are often constructed: one unit excludes all large animals; another excludes livestock but permits entry by big game. The National Academy of Sciences—National Research Council Subcommittee on Range Research Methods (1962) recommended a total exclosure not smaller than 1 acre and a livestock exclosure not smaller than 5 acres. Steel and Torrie (1960) also noted the advantages of small units and point out that their use leads to smaller blocks. The decrease in block size has the advantages of increasing between block difference and minimizing the variation among experimental units within blocks.

During the planning of an experiment, consideration must also be given to the shape and orientation of the experimental units. Pastures on which the ratio of length to width is from 1:1 to 4:1 have been recommended specifically for grazing experiments (Joint Committee 1952). To achieve maximum variation among blocks and minimum variation among units within blocks, the individual experimental units should be long and narrow and the block approximately square (Steel and Torrie 1960).

On ranges where fertility or moisture contours appear, the most precision is obtained when the long sides of experimental units are perpendicular to the contours or parallel to the direction of the gradient. The layout of the tract available for study, distribution and location of water, distribution and condition of vegetation, and the class of livestock also must be considered. In sheep grazing studies, for example, long, narrow units where topography is rolling or sloping can be particularly troublesome. Sheep bed on high points, and the application of a uniform grazing intensity is difficult or impossible when the pasture is long and narrow.

Long, narrow units increase cost of fencing, lengthen the trailing distance to corrals, and may increase the watering facilities. Since animals tend to patrol fences, grazing uniformity may be reduced if the units are extremely long and narrow.

REPLICATION

When a treatment appears more than once in an experiment it is said to be replicated. The functions of replication are (Steel and Torrie, 1960)—

1. To provide an estimate of experimental error. Without replication, there is no way to determine whether observed differences are due to treatment effect or to inherent variation in the experimental material.

2. To improve the precision of an experiment by reducing the standard deviation of a treatment mean.

3. To increase the scope of inference of the experiment.

Factors influencing the number of replicates needed include—

1. The degree of precision required.
2. The size of the basic experimental error involved (including error of sampling).
3. The number of treatments.
4. The degrees of freedom for error when number is less than 20.
5. The design.
6. The cost and facilities items.

Cochran and Cox (1950) have prepared tables with which the researcher, armed with some knowledge of the coefficient of variability of his material, can approximate the replications needed for various levels of precision. Replications for grazing studies, expanded by the Joint Committee (1952), are presented in table 1. Four treatments in a randomized block design were assumed in developing data in the table, but the values change little if there are more treatments. If there are fewer treatments, the values should be checked by the formula presented by Cochran and Cox (1950, p. 20). The equation is based on the assumption that increased replication steadily decreases the standard error of the difference between two treatment means. This relationship holds unless more heterogeneous material or faulty techniques are used because of expansion of the experiment.

TABLE 1.—*Approximate number of pastures per treatment necessary to have an 80-percent chance of detecting specified differences when using the two-tailed "t" test at the 5-percent level*

Difference desired to demonstrate (percent)	Coefficient of variability						
	4	8	12	16	20	24	28
	No.	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
5	11	41	91	----	----	----	----
10	4	11	24	41	63	91	----
15	3	6	11	19	29	44	60
20	2	4	7	11	17	23	31
30	2	3	4	6	8	11	14
40	2	2	3	4	5	7	9

Replicates of most grazing experiments have been installed at a single location. If replicates for an experiment can be installed at dispersed locations, the scope of inference of the experiment is considerably increased. Such replication in space is often prohibitively expensive with experiments involving large grazing animals and probably will remain the exception rather than the rule in grazing studies.

Most grazing experiments are conducted on the same pastures for a number of years. Although this length of treatment increases confidence in the results by providing a better sample in terms of growing conditions for vegetation and producing condition for animals, Federer (1955) has pointed out that successive annual measurements on the same plots include both direct and residual effects of treatments. True replication in time can be achieved by repeating the experiment in different years on different plots. Years also constitute replication in annual pastures which are reseeded and reallocated every year. True replication in time is expensive, but the additional information may justify the expense in some experiments.

SAMPLING WITHIN THE EXPERIMENTAL UNIT

Cost considerations usually preclude measurement of the entire experimental unit in grazing studies. The common procedure is to measure a number of randomly or systematically located sampling units within each experimental unit. When such a plan is adopted, optimum allocation of the sampling and experimental units is required. Suppose, for example, that 30 sampling units can be installed for each treatment. Should these 30 units be used to install three replicates with 10 sampling units in each experimental unit or would greater efficiency be obtained by installing 10 replicates with 3 sampling units each? Answers to this problem are intimately involved with the factors affecting number of replications.

Estimates of the following items must be available to evaluate optimum allocation:

1. σ^2_s, the sampling error component of variance for the response being studied.
2. σ^2_e, the experimental error component of variance for the response being studied.
3. C_s, the cost of installing and measuring a sampling unit throughout the life of the study.
4. C_e, the cost of installing, maintaining, and operating an experimental unit independent of sampling unit costs.

The mean square estimates can be obtained from previous experiments or from sampling studies similar to the Caloosa analysis which led to the variance curve shown in figure 1. Estimation of the cost figures will involve careful consideration of anticipated construction costs (fences, watering facilities, etc.) and expected time and material requirements for the installation and measurement of a sampling unit.

The appropriate formulas for estimating the sampling fraction (P) are given by Federer (1955) as

$$P=\sqrt{\frac{C_e f}{hC_s(1-f)}}$$

where

h=total number of available sampling units in each experimental unit

$$f=\frac{\sigma_s^2}{\sigma_s^2+h\sigma_e^2}$$

The use of these equations will be illustrated with selected data from the Caloosa sampling study. Computations will be made for anticipated experimental units of 10 acres with sampling units of 48 square feet. Estimated variance components from the previously mentioned sampling study for *Aristida stricta* were

$$\sigma_s^2=33{,}374$$

$$\sigma_e^2=27{,}149$$

Hence,

$$h=\frac{10\times 43{,}560}{48}=9{,}075$$

$$f=\frac{33{,}374}{33{,}374+(9{,}075)(27{,}149)}$$

$$=.00013544$$

$$P=\sqrt{\frac{C_e}{C_s}\;\frac{.00013544}{9{,}075(.99986456)}}$$

$$P=.000122\sqrt{\frac{C_e}{C_s}}$$

Thus, if the ratio of C_e to C_s was estimated at 100 to 1, the suggested sampling fraction would be calculated as .00122 or a sampled acreage (A) per experimental unit of

$$A=.00122\times 10 \text{ acres}=.0122 \text{ acre}$$

or

$$.0122 \text{ acre}\times 43{,}560 \text{ sq. ft.}=531.4 \text{ sq. ft.}$$

ASSIGNING TREATMENTS TO EXPERIMENTAL UNITS

The assignment of the treatments to the experimental units should always be accomplished using some process of randomization. Without proper randomization, an otherwise satisfactory design generally is ruined since no satisfactory estimate of experimental error is available. Cochran and Cox (1950) summarize the virtues of randomization quite succinctly with the statement: "Randomization is somewhat analogous to insurance, in that it is a precaution against disturbances which may or may not occur, and that may or may not be serious if they do occur."

TWO EXAMPLES OF GRAZING STUDY LAYOUT

Two examples, illustrating some of the problems of layout of grazing experiments and the type of information which can be used in planning future experiments, are presented below. The Caloosa Experimental Range is located in southern Florida; the Central Plains Experimental Range is in north central Colorado.

Southern Pine Flatwoods: Caloosa Experimental Range

The 1,600-acre range is divided into twelve 90-acre experimental units and two replacement pastures (fig. 2). The layout was designed for a study of the effects of three rates of stocking on vegetation and cattle. These rates allow approximately 15, 20, or 33 acres per cow per year, but adjustments in these rates are made periodically for variations in herbage production to maintain 70, 50, or 35 percent use of the key forage species. The ratio of length to width in the experimental units varies from 2:1 to 4:1. Access from each pasture to a centrally located corral is by narrow lanes. Water for each pasture is pumped from shallow wells. Mineral and feed bunkers initially were located away from water near the center of each pasture, but because of access problems during the summer rainy season, these facilities were moved nearer the access lanes.

Three distinct vegetation types are recognized: Pine-palmetto upland, wet prairie, and fresh water marsh. Within each experimental unit, sampling was segregated on the uplands and the wet prairie; the marsh type was not sampled because of flooding and other inherent sampling difficulties.

A variety of soil types—all fine sands—were mapped. Moisture or fertility gradients do not exist between units on the Range, and no basis for blocking was apparent. Consequently, grazing treatments were assigned completely at random to the experimental units. A system of alternate grazing requires two pastures per experimental herd so that there are only two true replications of the three grazing treatments. However, after each 4-year cycle, the alternate pastures will have received similar treatments, and the number of replications for vegetation data will be four rather than two.

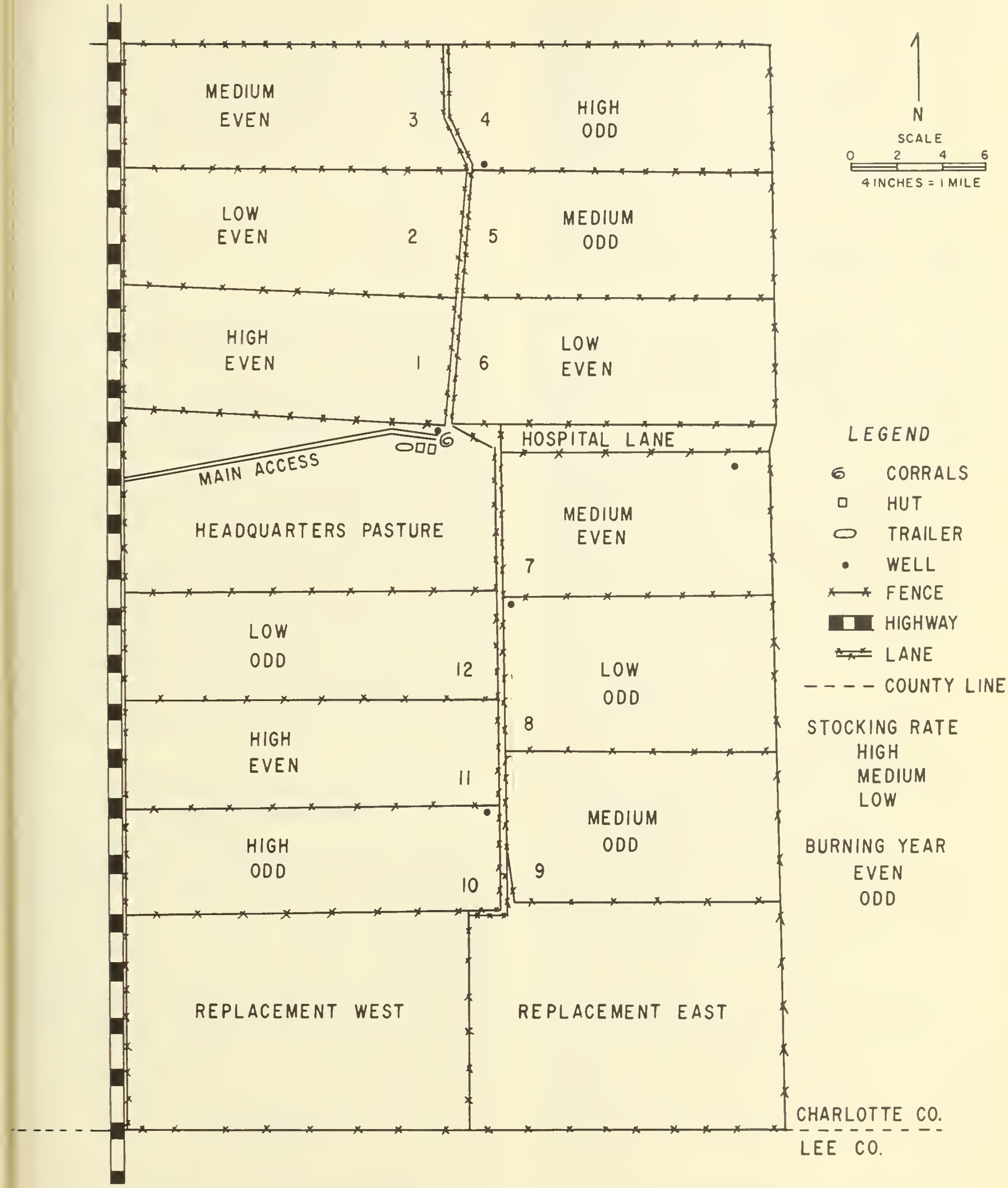

Figure 2.—Pasture layout, Caloosa Experimental Range.

The more extensive upland type was divided into four strata per pasture. Two random clusters of four plots, each containing 9.6 square feet, were sampled in each stratum. Two clusters were located at random in the wet prairie type. A double sampling method was used in obtaining herbage weight for six major species or groups on each plot. Data were electronically processed to produce summaries of herbage weight for species and groups by range types for each experimental unit.

In summary, five techniques were used to improve the efficiency of sampling vegetation: (1) Ecological segregation; (2) stratification; (3) clustering; (4) double sampling; (5) electronic data processing.

Herds of 6 to 12 native Brahman cows per pasture complete the experimental units. A nucleus of experimental animals is maintained, but harvesters are added or removed as herbage production in the pasture varies. Cows were selected as pregnant 4-year-olds in 1956, and all herds were grazed at the same rate until 1958. Cows were reassigned to experimental herds in 1958 by weight and pregnancy stratification to ensure uniform herds *between* pastures. Weights of cows within a herd of eight cows, for example, varied from 540 to 810 pounds. Available land, herd size, and range carrying capacity determined the size of the experimental pastures.

Responses obtained during the first 4 years of the study have been analyzed, and some of these data are presented as research planning information (table 2). During the first 3 months cattle are on recently burned ranges, *Aristida stricta* is the primary herbage component in their diet. The average volume of *Aristida* available during this period was 164 pounds per acre (ovendry); the standard deviation per pasture was 14 pounds per acre; and the coefficient of variation on recently burned ranges was 8.5 percent. Production of *Aristida* increased 19 pounds per acre in the pastures stocked at a high rate, or a percentage increase over low rate stocking of 12 percent. With only two replications, the least significant difference which could be detected, applying data from table 1, would be 40 percent. If data from alternate pastures improve replication of vegetation data to four replications, 20-percent differences might be significant.

The average production of *Aristida* for a 2-year period between burning cycles was 1,516 pounds per acre; the standard deviation, 207 pounds per acre; and the coefficient of variation, 14 percent. The maximum difference between rates of stocking was 402 pounds, or 22 percent. About nine replications would be needed to detect this difference.

The coefficient of variation for adjusted calf weaning weights was 5.7 percent. After 4 years

TABLE 2.—*Research planning data from the Caloosa Experimental Range grazing intensity study*

Years (number)	Treatment difference	Coefficient of variation	Replications needed [1]
PRODUCTION OF ARISTIDA ON RECENT BURNS			
	Percent	*Percent*	*Number*
4	12	8.5	9
AVERAGE PRODUCTION OF ARISTIDA			
2	22	14	9
ADJUSTED CALF WEANING WEIGHT			
4	0	5.7	----------

[1] For significance at the 5-percent probability level, from table 1.

there were no significant differences between rates of stocking in calf weaning weights; the present study design would detect weight improvements in the order of 20 to 30 percent.

Most of the native Brahman cows used in this study have calved only in alternate years. This variation contributes considerably to the difficulty in evaluating animal responses.

Yearly variation in herbage production is great in most range grazing studies. On the Caloosa, from 1957 through 1960 production of *Aristida stricta* on recent burns averaged 105, 168, 237, and 147 pounds per acre, respectively. Total herbage production averaged 256, 364, 592, and 296 pounds per acre. The considerable variation in these production figures illustrates the importance of extending grazing studies over a number of years.

Short-Grass Plains: Central Plains Experimental Range

One of the more thoroughly reported range experiments involved a study of vegetation and cattle responses to different intensities of grazing on short-grass ranges in the central Great Plains (Kipple and Costello, 1960). Three rates of stocking were applied on 12 range units, each one-half mile wide and 1 mile long. Pastures were blocked in units of three, each block representing a different combination of short-grass range subtypes. In 1939, grazing intensity was assigned at random to one pasture in each block. One- or 2-acre cattle exclosures were established in each pasture. These were used to compare grazed and ungrazed range in evaluating range condition, and to study vegetation changes due to factors other than domestic livestock grazing.

The minimum yearling heifers assigned to pastures varied mostly between 8 and 16; as many as 45 animals were used in some high stocking-rate

pastures. Treatments were maintained for 15 years.

Samples of the various responses are presented as research planning data (table 3). The analysis of variance of herbage production (blue grama plus buffalograss) for a period early in the study (1940–1942 mean) shows the effectiveness of blocks in reducing experimental error. Fifty-five percent of the total variation was removed by blocks:

Source of variation	*Difference*	*Sum of squares*
Blocks	3	102, 234
Rates of stocking	2	13, 455
Blocks x rates	6	69, 264
Total	11	184, 953

TABLE 3.—*Research planning data from the central Great Plains grazing intensity study*

Years (number)	Treatment difference	Coefficient of variation	Replications needed [1]
PRODUCTION (POUNDS PER ACRE) BLUE GRAMA PLUS BUFFALOGRASS			
	Percent	*Percent*	*Number*
4	13	17	28
9	41	15	4
RANGE CONDITION RATING			
15	82	13	2
SEASONAL WEIGHT GAINS OF CATTLE			
10	22	9	4

[1] For significance at the 5-percent probability level, from table 1, p. 127.

Significant effects of treatments were detected after 8 years for herbage production, 10 years for seasonal weight gains of cattle, and 11 years for range condition ratings.

Significant differences in the layouts of the two grazing studies are summarized below:

Item of layout	*Study* Caloosa	*Study* Central Plains
Design	(1)	(2)
Acreage of pastures	90	320
Type of cattle	(3)	(4)
Replications	2	4
Pastures per replication	2	1
Length of study (years)	8	15

[1] Completely random.
[2] Randomized block.
[3] Cow-calf.
[4] Yearling heifers.

CONCLUSIONS

General guidelines to assist the researcher in developing a proper layout for his experiment have been presented. The researcher must provide some input data to achieve the most efficient design for his study area. In some cases, the researcher must conduct pre-experiment studies to obtain planning data; in many cases, the planning data are available in his files, and in a few cases, design planning data have been published.

Five considerations in layout of grazing studies merit special emphasis:

1. Replication in most past (and many present) grazing studies has been inadequate. This probably has been the most serious limitation of designed studies.
2. Efficient sizes of experimental units and blocks of vegetation should be determined. The most efficient unit for vegetation study may be considerably smaller than the unit commonly used.
3. Design planning data for major range types should be summarized, at least, and published, if possible. The need for such data is acute for browse ranges; data from sheep experiments is also meager.
4. Researchers should use available statistical planning data.
5. In planning an experiment, pertinent biological information from previous studies should be carefully evaluated and judiciously utilized in selecting the experimental layout. A list of grazing experiments from which experience can be drawn follows:

1. Miles City, Mont.—shortgrass, yearlong, cattle and sheep
2. Manyberries, Alberta—midgrass and shortgrass, yearlong, cattle
3. Woodward, Okla.—midgrass and tallgrass, seasonal and yearlong, cattle
4. Mandan, N. Dak.—midgrass, yearlong, cattle
5. Central Plains—shortgrass, yearlong, cattle
6. Manitou, Colo.—pine–grassland, summer, cattle
7. Black Mesa, Colo.—subalpine fescue, summer, cattle
8. Jornada, N. Mex.—desert–shrub, yearlong, cattle
9. Near Albuquerque, N. Mex.—crested wheatgrass, summer, cattle
10. U.S. Sheep Station, Idaho—sagebrush–grass, spring and fall, sheep
11. U.S. Sheep Station, Idaho—seeded small pastures, spring, sheep
12. Starkey, Oreg.—pine–bunchgrass, summer, cattle
13. Squaw Butte, Oreg.—sagebrush–grass, spring–summer–fall, cattle
14. Benmore, Utah—crested wheatgrass, spring–summer, cattle
15. Ephraim, Utah—crested wheatgrass small, short spring, sheep
16. Desert Sta., Utah—desert shrub, winter, sheep
17. Santa Rita, Ariz.—desert shrub, yearlong, cattle
18. Sonora, Tex.—shrub–grass, yearlong, sheep, goats, cattle
19. San Joaquin, Calif.—annual range, yearlong, cattle
20. Harvey Valley, Calif.—pine–bunchgrass, summer, cattle
21. Bighorn, Wyo.—subalpine, summer, cattle
22. Alapaha, Ga.—Slash–longleaf–wiregrass, yearlong, cattle
23. Alexandria, La.—longleaf–bluestem, yearlong, cattle
24. Caloosa, Fla.—slash–wiregrass, yearlong, cattle
25. Frying Pan, N.C.—pond pine–cane, summer, cattle.

SPECIAL CONSIDERATIONS IN THE DESIGN OF GRAZING EXPERIMENTS

H. L. Lucas [1]

This paper will be devoted to some special types of grazing experiments, and also to two other important questions—supplemental feeding and fixed vs. variable rates of stocking. General, but integral, consideration will be given to the effects on both range and animal of different procedures, and to the translation of results into management guides.

THE KEY ROLE OF SWARD STATUS AND ITS TIME TREND

The general framework for this paper was given in my first paper. There it was pointed out that sward status and its time course provide a reference axis about which the whole system can be viewed. Sward status and its time course (plus side conditions) determine the performance of the sward. Also, sward status and its time course, operating through the forage produced and in conjunction with kind of animal and feed supplement, determine production per animal. In the present paper, it will be shown that the effects of items ordinarily thought of as treatment variables for the pasture *per se* (i.e., side conditions, including stocking rate, degree of utilization, season of use, fertilization, etc.) are predominantly expressed in sward status and its time course. The effects of factors applied to the animals, such as supplemental feeding, are not completely reflected in sward status.

SWARD STATUS AS A TREATMENT VARIABLE

Since man can control, either directly or indirectly, the status of a sward, sward status and its time course clearly should be considered one of the treatment variables. This is so regardless of whether the interest is in the factors affecting sward performances or in the animal's response to sward characteristics. Results should be interpreted, therefore, in terms of both sward status and other experimental variables. To permit such interpretation the experimenter must "force" sufficient variation in sward status and its time trend.

Classes of Special Studies

In view of the foregoing remarks, the term special studies brings to mind principally two classes of work:

1. Sward-oriented experiments; i.e., experiments designed primarily to study the factors affecting sward performance.
2. Animal-oriented experiments; i.e., experiments designed primarily to study the sward factors affecting animal performance and how things done to the animals (e.g., supplementary feeding) condition the animal reaction.

Critical Measurements

Sward-Oriented Experiments.—For experiments devoted to sward behavior it is obviously critical to be able to describe sward status and experimental treatments in terms that are meaningful relative to the plants. Presumably description in terms of functional plant parts, present and removed, and in terms of root and stubble stores is the proper approach. This applies particularly to sward status itself, and to treatment factors such as distribution and rate and frequency of defoliation. It is also necessary to relate such measures on the sward to the treatment factors imposed and to sward performance.

Sward-oriented experiments can be done without animals, but only those in which animals would be involved will be considered here.

Animal-Oriented Experiments.—For experiments devoted to animal behavior it is critical to be able to describe factors affecting the animal in terms that are meaningful relative to the animal. Presumably description of the sward offered in terms of animal nutrients and their distributions is the proper approach. Attention should be given to the matter of forage available per animal and to accessibility if these are restrictive factors in a particular experiment.

Integration of Sward-Oriented and Animal-Oriented Results.—In order to make management recommendations, results from the two classes of experiments must be properly integrated. This requires the ability to translate between the plant and animal frames of reference. For example, the results of sward-oriented experiments, which could be expressed in terms of plant parts harvested, should be capable of conversion into terms of nutrients harvested. Conversely, in animal-oriented experiments, it is desirable to translate the descriptions of sward status and forage consumption, which probably would be expressed in terms of animal nutrients, into plant parts, if such is possible.

Theoretically, the conversion from plant parts to animal nutrients is always possible via chemical analysis. Just how to do it well is, of course.

[1] Many thanks are due Miss Mary Ann Cipolloni, Mrs. H. L. Lucas, and Dr. and Mrs. R. G. Petersen for help in preparation of this manuscript.

not yet known. The converse translation may not generally be possible because there are probably many fewer critical nutrients than critical plant parts (different maturities of different parts of different species). Thus, it seems necessary to use both plant- and animal-oriented measurements in the animal-oriented studies.

Types of Designs

Many special types of experimental designs can be visualized, but discussion will be restricted to two fairly broad types, and these will be considered only in a general way. The two types are—

1. Treatment-sequence experiments; i.e., experiments involving sequence of treatments on pastures large enough to support one or more animals continuously for some relatively long period.
2. Small-pasture experiments; i.e., experiments with pastures so small that even a single animal cannot be supported for more than a few days, or even a few hours.

Both types can be used for both classes of studies previously noted.

Designs for treatment-sequence experiments are particularly important because of the need to vary the management of many types of range pastures from one time of year to another in order to ensure sward health. There is also the need to manage animals (including supplementary feeding) in a periodic way because of seasonal variation in amount and quality of forage available. Designs for small-pasture experiments are important because specific facets of the system can be critically studied with them.

Stocking Rate and Feed Supplements

Since stocking rate and supplementary feeding are directly controllable by man, they are clearly treatment variables. It should be stressed that the two variables need not be *pre-set;* i.e., their levels need not be decided prior to an experiment and such levels adhered to rigidly. Presetting can be used, of course, but it does not seem desirable as a general rule for pasture work. Instead, it ordinarily seems more reasonable to have the levels partially or completely *performance-determined;* i.e., to have the levels and the time courses of levels determined by the status and the past performance of sward and/or animal.

Measurement of Results

In many experiments on treatment sequences, animals can be used to measure forage yield and quality. However, this usually will not be possible in small-pasture experiments.

SWARD-ORIENTED EXPERIMENTS

Although, theoretically, animals are not required in experiments designed to study sward behavior (Lucas 1960), they are extensively used because researchers are not able to simulate animal action with sufficient accuracy. In many such studies, the animals serve only as a treatment device; measurements are made only on the sward. The status of the sward, and the type and the amount of forage produced and eaten, are measured in some appropriate way; these are then correlated with each other and with the treatment factors.

Designs Involving Sequences of Treatments

There is need in practical pasture management to control the time trends of sward status so that desired sward character and vigor are maintained, or attained as rapidly as possible. For example, at some times of year, light grazing may be necessary in order to ensure proper accumulation of the root and stubble reserves. This need has been well recognized, particularly in range research, and many experiments in which pastures are grazed periodically (with grazing and rest periods of varying lengths) have been and are now being run.

The words, rotational grazing and changeover trials, are often associated with such studies. However, the idea involved is really not the same as the idea of rotational grazing and is much different than the idea of changeover trials. Rotational grazing connotes rather short-term cycling. Changeover trials involve the idea that comparisons of different treatments on the same individual are quite precise because variation between individuals is eliminated from treatment contrasts.

One of the problems in changeover trials is the possible existence of carryover effects, and, unless such effects do not exist, or unless some adequate way of considering them in analyzing results is known, treatment comparisons are vitiated. Carryover effects of stocking rate, for example, could be very strong on pastures, and since they are obviously complicated, it seems certain that proper analysis of results would be almost impossible. Changeover designs do not appear, therefore, to have a place in pasture research devoted to learning the reaction of sward to treatment.

The proper way to look at the problem, apparently, is as follows: One subdivides the treatment cycle (cycle length might be 1 or 2 years) into a number of critical time periods, which

probably should be of different lengths. For each period there exist alternatives (treatments) that might be done to the pasture. For example, consider a cycle with three periods. There might be three alternative treatments for the first period, two for the second, and four for the third. Thus, there would be 24 ways of treating the pasture during a cycle.

I know only of some very preliminary work on design and analysis of experiments of this type. One alternative is to use only part of the possible treatment sequences and to employ the initial conditions for a given period in a covariance-type approach in order to interpret results for that period.

Clearly, there is room for much thought and research about design and analysis of experiments involving sequences of pasture treatments.

Small Pasture Experiments

In the present context, the pastures involved can be subjected only to intermittent, short grazings. This raises a question about how results from such studies apply to range research. This question can be resolved, however, by referring to figures 1 to 4 of my first paper.

Suppose the treatment variables are sward status at the time the animal goes on the plot (initial sward status) and amount of forage that the animal is allowed to remove. Then, if proper measurements of initial sward status, forage produced, and forage consumed can be made, the data permit two important relations to be estimated:

1. The relation of amount and type of forage produced to sward status.
2. The relation of the way the animal treats the sward to the amount and type of forage available.

In such studies it is necessary to offer the animal an adequate variety of different sward statuses in order to control as much as possible the amount of forage consumed per animal over a sufficiently wide range, and to make a sufficient number of measurements in terms that are meaningful relative to the sward.

By thinking of the factors involved in the system, one can imagine many sorts of critical experiments regarding sward behavior that can be done with small plots using the animal as a treatment tool.

ANIMAL-ORIENTED EXPERIMENTS

Although many facets of animal response on pasture can be studied by feeding cut forage and other harvested feeds, there are certain ones which require grazing (Lucas 1960). In particular, there is the relationship of type and amount of forage consumed to type and amount of forage available. Another important factor is the way an animal reacts to a time trend in, or a periodic fluctuation of, the pasturage.

As regards measurement, it is critical to describe sward status and other items in terms that are meaningful relative to the animal.

Designs Involving Sequences of Treatments

Some attention was previously devoted to the application of sequences of treatments to the pastures. Now, we consider applying sequences of treatments to the animals on the pastures. Different sequences can be obtained by moving the animals from one "kind" of pasture to another, or for example by periodically changing the grain feeding level while the animals are kept on the same or the same "kind" of pasture.

We note again that the idea involved is not the same as the one of rotational grazing. In rotational grazing, the animals move from pasture to pasture, but the "kind" of pasture is always the same. Trials of the true changeover type might be used in the usual way for level of grain feeding, or for moving animals from one "kind" of pasture to another; however, these are particularly valuable only with dairy cattle.

Focus, then, is again on the idea of subdividing the grazing season into critical periods and studying various alternative treatments in each period. For example, there might be several alternatives for kind of spring pasturage, several for summer (e.g., irrigated crops as contrasted to range grazing), and several for fall. The problems of design and analysis associated with many possible sequences are in essence the same as those mentioned previously.

Small Pasture Experiments

The general ideas involved are analogous to those considered from the standpoint of sward performance. Now, however, animal performance is of interest. Again, initial sward status could be a treatment variable. A second variable could be the length of time the animal is allowed to graze. Then, with proper measurements of initial sward status, forage produced, and forage consumed, and of important short-term aspects of animal behavior, information could be obtained on the relationship of type and amount of forage consumed (and of other behavior patterns) to type and amount of forage available.

Thus, by choosing appropriate kinds of measurements, and proper levels and admixtures of treatment variables, small pasture experiments can elucidate sward and animal behavior simultaneously.

FIXED VS. VARIABLE RATES OF STOCKING

There is continuing controversy on the question of fixed vs. variable rates of stocking. This controversy appears to stem from confusion on two matters.

1. There is confusion between different ways of varying the stocking rate.
2. There is confusion between the goals of research and the goals of a practical operation.

Confusion About Ways of Varying Stocking Rate

Two types of variation of stocking rate must be distinguished: (1) stocking rate can be varied from time to time on a given pasture (the put-and-take procedure), and (2) different pastures of the same type, which are otherwise treated the same way, can be subjected to different stocking rates.

Confusion Between Research and Practices

The remark is often heard that put-and-take stocking should not be done in experimental work. This is because the farmer or rancher has a constant number of animals on his premises and the results of put-and-take experiments do not apply to practice. This attitude has never seemed very sound to me. A farmer can subdivide his pasture area, harvest forage mechanically in pasture-flush periods for backfeeding in pasture-slack periods, provide high-yielding cultivated pastures in slack periods, buy feed supplements, or sell or store excess mechanically harvested forage. Thus, he actually can vary the number of animals on a given area of pasture, or conversely can vary the area allotted to a given number of animals.

The important point is that research should provide the wide variety of information necessary for a farmer to make intelligent decisions for his particular operation. This requires the use of various time patterns of stocking rate, and various average stocking rates, in pasture experimentation.

Put-and-Take Stocking

The basic reason for use of put-and-take stocking is to control the time trend of sward status in a way thought appropriate to the purposes of an experiment. One problem is that judgment about putting and taking is quite subjective. As the method is ordinarily used, the comparisons of factors other than stocking rate can be biased, because manipulation of stocking rate can itself affect forage production and quality. That is, adjustment of stocking rates can be made so as to put a given treatment at a disadvantage compared to the others.

Note that the procedure of holding animal numbers constant through time on a given pasture can be thought of as the limiting case of the put-and-take method in which the adjustment of animal numbers is nil.

Attainment of Different Average Grazing Pressures

Mott and Lucas (1952) noted that the bias just mentioned can be overcome by using three or more average stocking rates on each treatment under study. Their idea is that the upper and lower stocking rates should be far enough apart so that every treatment is well overstocked and well understocked, and that one of the intermediate stocking rates is nearly optimum for the particular treatment.

It has been said that the alternative to put-and-take stocking is to use three or more rates of constant stocking. This statement is not true. Different average stocking rates can be obtained with the put-and-take method as well as with the constant-number approach. With the put-and-take method, the easiest way is to vary pasture size and to place the same number of animals on all the pastures. This number is determined by what is thought to be optimum for one of the middle-sized pastures. The time changes in animal numbers are also made equal on all pastures; these changes are governed by the sward control desired on the middle-sized pasture. Constant stocking at different rates is just a special case of put-and-take stocking at different rates.

For each stocking rate on each treatment, results can be computed as outlined in my first paper. An optimum stocking rate can then be estimated for each treatment, and the different treatments can be compared at their optima.

SUPPLEMENTARY FEEDING

Feed supplements can be and are generally employed to prevent poor animal performance. However, any time animal performance is poor, and the trouble is not attributable to factors such as disease or weather, the cause is poor quality of forage (including deficiency of specific nutrients), poor accessibility of forage, or scanty forage supply. Regardless of the reason, feeding of the proper kind of supplement will improve production per animal, and the amount fed will govern the magnitude of improvement. Supplements need not be concentrates; they also can be harvested and preserved forages.

If the poor performance is traceable to poor accessibility, it may be more economical in practice to improve accessibility than to feed supplements; e.g., by increasing the number of watering places. If the trouble is traceable to insufficient forage available per animal, a lower stocking rate may be preferable to supplementary feeding, but the answer depends on economic factors. If the trouble is traceable to low amounts of forage per acre, thus making it impossible, because of travel requirements, for the animal to gather enough forage per day, supplementary feeding is the only immediate way to overcome the problem. In the long run, of course, the amount of supplementary feeding required might be reduced or, in some situations, rendered nil, by increasing the productivity of the range through seeding, brush control, etc. Similarly, if forage quality is poor, supplemental feeding is necessary. The important point is that supplementary feeding, particularly energy (and requisite protein feeding), is often the only immediate way to improve animal performance on pasture.

Types of Supplementary Feeding

It is convenient to think of two types of supplementary feeding, emergency and planned. The two types have many similarities, both being treatment variables, but there are also some differences. Emergency supplementation is inherently periodic in nature and is performance-determined. Ordinarily it consists of roughages, which are fed in amounts and for periods of time just sufficient to prevent undue stress on the sward and/or the animal. Planned supplementation ordinarily involves concentrate feeding but can involve forages. It can be periodic and performance-determined, but it does not have to be. The experimenter or practical grazier can govern the amounts and the times of feeding to suit his purposes. Sometimes, emergency supplementation might be needed in addition to planned supplementation.

In the experimental context, it is sometimes said that the amounts and the times of feeding of emergency supplements should be the same on all treatments. This is not necessary, although it may often be desirable. If the sward and the supplements can be properly measured, the two sets of measurements can be jointly considered when interpreting sward performance and animal performance. One way is to make corrections via a feed unit system. Another way is by devices such as covariance analysis, but the latter recourse is open only if proper replication has been made.

Under planned supplementation, too, proper measurements on both sward and supplement and proper analysis of the data must be made to enable proper interpretation.

Supplementary Feeding in Grazing Trials

There seems to be considerable prejudice against the feeding of supplements in experimental work, except in emergencies or to supply specific deficient nutrients. In this connection, the following two statements are commonly heard:

1. In practice, it just does not pay to feed concentrates on pasture, other than in small amounts, except to overcome specific deficiencies.
2. Feeding of concentrates, other than in small amounts, vitiates the experimental comparison of pastures.

Justification for the first statement is that pasturage is cheaper than concentrates and, with the meat animals at least, the extra quantity or quality of animal product does not pay for the concentrate. It is recognized that this argument does not pertain to good dairy cattle; however, the term, "small amounts," is usually merely replaced by "moderate amounts" when it does. Two matters cause one to seriously question the justification. They are—

1. For many situations, there does not seem to be any supporting data at all.
2. For other situations, the data that are available are in terms of production per animal, or, if in terms of animal production per acre, they have been obtained from improperly conducted experiments.

Justification for the second statement is something to the effect that concentrate feeding prevents full expression of pasture differences. This is not true, but can be ostensibly true, if experiments are not properly conducted, proper measurements are not made, or interpretation is improper.

The Effect of Supplements on Animal and Pasture Performance

Several points are important here:

1. If the supplement provides nutrients (other than energy) in which the forage is deficient, supplementary feeding can result in an increase of forage consumption and, hence, an increased production per animal greater than that expected from the energy value of the supplement alone.
2. If the supplement is principally a source of extra energy, the forage consumption per animal can be decreased, with a resulting increase in carrying capacity of the pasture.
3. The supplemental feeding can change the type of forage consumed; i.e., it can shift the

maturity or the ratios of different plant parts and different species consumed, thereby shifting sward status and subsequent pasture performance.

Point 1 describes the situation for which the value of supplements is well recognized, but points 2 and 3 seem to be overlooked most of the time. Point 2 seems ordinarily to be much more important than point 3 for humid-region cultivated pastures, but on range both probably are of significance.

Concerning point 2: The importance of point 2 is well illustrated by data[2] on the effect of grain feeding on Indiana cultivated pastures. Four types of testers (animals wintered at four levels of grain feeding in dry lot) were present on each pasture. The results in table 1 are averaged over the four types of testers. Put-and-take stocking was used in order to hold sward status the same at the different grain levels. Note the large increases in carrying capacity, daily gain, and gain per acre occasioned by grain feeding.

There is little reason to doubt that similar results would occur on ranges. Cost and price patterns must be considered in using such results, but that is not the basic problem. The basic matter is to establish the relationships. These plus the economic factors then provide the basis for proper management decisions.

Concerning point 3: There is apparently no data available to illustrate the inference. That the type and amount of supplement supplied can affect the type as well as the amount of forage consumed seems clear enough. For example, animals receiving concentrate supplement could well choose a greater proportion of "rough" forage than animals receiving no supplement. Hence, supplementary feeding could be a practical means of shifting sward status and subsequent sward performance in a desirable way, via changing the relative amounts of different species consumed, or of the parts of plant consumed on a given species.

TABLE 1.—*Performance on pasture and carrying capacity as affected by level of grain supplement fed*

(INDIANA CULTIVATED PASTURES)

Measurement	Supplement level			
	None	One-third	Two-thirds	Full fed
Average daily gain (pounds)	1. 07	1. 31	1. 52	1. 70
Steer days per acre (days)	212	258	306	401
Gain per acre (pounds)	218	316	445	661
Relative carrying capacity	1. 00	1. 21	1. 44	1. 89
Net return/steer	$14. 71	$15. 14	$15. 45	$12. 96
Net return/acre (relative)	$14. 71	$18. 32	$22. 25	$24. 49

[2] Personal correspondence with G. O. Mott, 1961.

KIND, NUMBER, AND SELECTION OF LIVESTOCK FOR GRAZING STUDIES, AND ANIMAL MEASUREMENTS MOST SUITED FOR EVALUATING RESULTS

W. M. JOHNSON AND W. A. LAYCOCK

Any discussion of the factors set forth in the title of this paper must, of necessity, be general in nature. Strengths and weaknesses of the various aspects can be pointed out and discussed. Obvious limits of application can be reiterated. Literature can be reviewed. In the final analysis, however, much depends on the specific objectives of the particular study, and final decisions must fit within the framework of these specific objectives.

The principal reason for using livestock under controlled conditions is that we have not learned how to duplicate artificially the choice of plants and plant parts grazed by animals, the trampling that results, and the application and distribution of fecal matter and urine. We must actually use the grazing animals to impose the treatments desired, or to evaluate in terms of animal response the effectiveness of other treatments applied to the vegetation or soil.

KIND OF LIVESTOCK

The kind and class of livestock to be used in a grazing experiment are dictated by the specific objectives of the study, the nature of the local livestock industry, and the kind of range to be studied. Some careful probing as to the needs for specific kinds of animals might come up with new and worthwhile approaches. Obviously beef cattle would not be used to evaluate high alpine sheep range. But what about the pika? For some purposes small animals can be used in pilot studies to predict large animal response, especially responses related to forage nutritional values, or in some cases to predict basic

information about the characteristics of herbage growth and utilization (Crampton 1939, Hedrick 1957). Certainly in the field of autecology the use of small animals as "pilot testers" should be considered. When small animals are used, the resulting diminution of trampling effects would have to be considered.

For some specific studies, multiple use by two or more kinds of animals must be considered. Some ranges might be more efficiently managed by grazing both sheep and cattle together or in rotation. Almost always there is dual use by domestic livestock and wild game. Whenever studies are made under these circumstances, the effects of the different kinds of livestock should be segregated either by measurements that recognize that they are grazed at different seasons or by using exclosures that permit access by one kind of animal but not the other.

Osborne and Reid (1952) state that, to determine the effect of grazing treatments by domestic livestock on vegetation, yearling heifers or dry or yearling ewes are probably most satisfactory. In some cases this is subject to criticism because these animals are not representative of the local industry. Under such circumstances Osborne and Reid state "use of the breeding herd is often to be desired, although by their use the research man is confronted with many problems."

The breeding herd operation provides a means of evaluating the reproductive potential of animals during the grazing treatment. In this evaluation the study must be of rather long duration, and yearlong in nature or at least provide for a uniform treatment of the animals when they are not on the study site.

A practical factor in the use of cows for studies of summer grazing is the problem of breeding. The pastures must be large enough to carry the proper ratio of cows to bulls, which sometimes means larger pastures than necessary for the study of vegetation response. This increases sampling problems. If the pastures are not of adequate size, bulls must service fewer cows, which is a costly procedure. These objections may be overcome by means of artificial insemination. The breeding herd is probably best adapted to studies involving yearlong management of animals or range.

Yearling steers or heifers or wethers or yearling ewes are often used in range grazing experiments. Since new groups of these are used each year, determining cumulative treatment effects on the animal is not possible. Also, conditions under which the animals are grown prior to being used on an experimental range affect their responses during the study period. This, to some extent, limits the application of the results.

In the authors' experience, yearling steers are perhaps the most easily handled animals for range grazing experiments. They usually have a quieter disposition than heifers, and if handled properly can be moved through the corrals and weighed with a minimum of time, effort, and disturbance of the animal. They tend to graze the gentler parts of a pasture, much the same as cows and calves. Usually heifers will graze higher on the slopes, farther away from water and in smaller groups than either steers or cows and calves. Reproductive functions may have a pronounced effect on the gain and disposition of yearling heifers. Steers or heifers are best adapted to short-season studies concerned with grazing intensity and systems of management on native or reseeded ranges.

Since a certain level of precision is sought in most research, the amount of variation in animal response to a treatment needs to be considered. The coefficient of variation of the weight gains of animals is one measure of this variability.

Limited data available to the authors indicate that weight gains for breeding cows were remarkably consistent when compared with gains for other classes and kinds of animals. The variability of weight gains for calves was twice that of cows, or 18 percent of the mean gain. Cow-gain plus calf-gain variation was also 18 percent of the mean.

Weight gains for yearling steers were less variable than those for yearling heifers, and the range of variability was also less. The average coefficient of variation for 16 groups of steers was 14 percent of the average gain in weight, and ranged from 10 to 23 percent. Yearling heifers had an average coefficient of variation of 18 percent and ranged from 7 to 36 percent.

Mature ewes were so variable that their use to evaluate weight gains in range grazing experiments is almost prohibitive. The average coefficient of variation of weight gains for 12 groups of producing ewes was 223 percent of the mean. The minimum variation was 50 percent and the maximum variation was over 1,000 percent. Weight gains of lambs were far less variable, and the range of variation closely approximated the variation for yearling steers. Weight gains of ewes plus weight gains of lambs had an average coefficient of variation of 22 percent of the mean and varied from 16 to 27 percent. One group of weight gains on wethers analyzed for variation revealed a coefficient of variation of 28 percent of the mean.

There is some indication that there are differences in weight gains between breeds of cattle. At the Manitou Experimental Forest in Colorado, 2 years of comparbale records showed an average coefficient of variability for Angus heifers of 10 percent and for Hereford heifers of 14 percent. In these studies the Angus yearlings were easier to handle in the pasture because

they were more gregarious. In the corrals for weighing and sorting, the Angus were much more excitable than the Herefords.

Based on this information and assuming that other factors regarding kind of animals to use in an experiment are equal, it would appear that yearling steers would be the most appropriate selection for grazing experiments with beef cattle. Cows could be considered if additional information on coefficients of variation would substantiate the apparent low variability found in this one observation. For sheep, lamb gains are least variable and lambs running with the ewes would therefore be a logical selection. It is possible that low variation in lamb gains is a function of dam-offspring relationship, and for this reason this approach should be used with caution. Most animal husbandmen prefer the use of yearling ewes or wethers, but very little information on these classes of livestock was available to the authors.

NUMBER OF ANIMALS

The number of animals to use in any given study is determined by the specific objectives of the study and the level of precision within which animal response to treatment is to be measured. Level of precision is a function of the variability among the individual animals. If gains are used as a measure of animal response, many factors must be considered: Sex, breed, ownership, quality, grazing treatment, and year. Some of these factors were discussed in the previous section.

Any decision on the number of animals to use for a given study should consider two factors. First, what level of precision would be acceptable? This would depend on the importance of animal response as part of treatment effects. Second, what would be the expected level of variability for the animals being studied? This can best be determined from an analysis of weight gain data gathered under conditions similar to the proposed study—if available.

The N values (table 1) are the number of animals needed to sample a given population of animals at various levels of probability. Theoretically, if 20 animals are needed to sample a population, this requirement could possibly be met by 2 replications of 10 animals or 4 replications of 5 animals. Replications increase the efficiency up to prescribed limits of error and might result in fewer animals being needed for an experiment.

At the Southern Great Plains Field Station (National Academy of Sciences, National Research Council, 1962, p. 133) 3 replications of 2 animals per treatment over a period of 8 years gave satisfactory precision to detect 15-pound differences in gain per animal between treatments.

Petersen and Lucas (1960) stated that "For quality measures like average daily gain, with fattening animals, pastures that will carry 3–6 animals appear to be of optimum size for experimental purposes. For quantity measures like effective total digestible nutrient yield, somewhat smaller pastures, carrying 1–3 animals for the duration of the trial are optimum." Lucas (1950) previously stated that "the optimum number of animals per pasture in the humid region is about seven for nutritive value studies and about two for yield studies."

TABLE 1.—*Number of animals necessary to measure animal responses based on various coefficients of variation and probability levels*

Coefficient of variation (percent)	Probability level, percent				
	5	10	15	20	25
	Number of animals				
9	22	5	2	1	1
10	27	7	3	2	1
11	33	8	4	2	1
12	39	10	4	2	2
13	46	11	5	3	2
14	53	13	6	3	2
15	61	15	7	4	2
16	69	17	8	4	3
17	78	20	9	5	3
18	88	22	10	5	4
19	98	24	11	6	4
20	108	27	12	7	4
21	119	30	13	7	5
22	131	33	15	8	5
23	143	36	16	9	6
24	156	39	17	10	6
25	169	42	19	11	7
26	183	46	20	11	7
27	197	49	22	12	8
28	212	53	24	13	8
29	227	57	25	14	9
30	243	61	27	15	10

Formula $N=\frac{t^2C^2}{p^2}$

where N=number of animals,
t=2.6,
C=coefficient of variation,
p=level of probability.

If animal response is not an important objective of the study, fewer animals probably would be needed and smaller study units could be established. In any study, sufficient animals should be used to insure normal behavior. Quantitative limits for this requirement have not been well established. At the Manitou Experimental Forest two yearling heifers were used in small

seeded pastures (2 to 5 acres). The animals behaved normally, probably because other animals were just across the fence. There was some tendency to "visit" in the fence corners, but there was no excessive trailing and the heifers did not appear to be restless (Johnson 1959).

SELECTION OF ANIMALS

The objectives of the study again dictate the selection of the animals in terms of kind, class, and number to be used. Within these stipulations the most important criteria for selection of experimental animals depends upon the application of results. In this connection the researcher has the choice of reducing variability by controlling the quality, management, ownership, and breed of animal, or accepting greater variability (which means larger numbers), but having his results apply to a wider range of conditions in animals.

For example, measurement of animal response in a study with Angus cattle may apply in some ways to all cattle, but specific quantitative results will apply only to Angus cattle. If the study is further restricted to steers, the results will apply only to Angus steers. If the steers are of good quality and have been overwintered to gain 1 pound per day, the results will apply only to Angus steers of good quality wintered at a high level of nutrition, and so on.

On the other hand, if both Angus and Herefords are used, and if both steers and heifers or even cows and calves are used from several ownerships (and thus usually several levels of quality and winter management) then the results will apply to the general type of livestock industry in practice locally. Such a study would require larger pastures and more complex sampling procedures.

Brothers (1958) and Hancock (1952) found that the use of selected twins reduced experimental error among animals. If the objectives of the study permit this approach, the use of such animals should not be overlooked.

Mott and Lucas (1952) state that selection of animals should include "grouping of animals into homogeneous blocks which are allotted across all pastures on all treatments—this may reduce effectively the errors for treatment contrasts." Green et al. (1952) also state that "it is only logical to group animals according to weight, stage of maturity, previous treatment, etc. and to allocate individuals in such a way that each group is proportionately represented." Finney (1957) states, however, that the disadvantages of grouping, or balance of animals in treatment groups, seem to outweigh the advantages, and suggests other design possibilities for such studies.

The health of the animal, obviously, is also of great importance. Animals that are lame, sick, or deformed probably will not respond in the same manner as those that are healthy. Also, animals that are accustomed to the type of forage and the terrain in the pastures to be grazed will respond in a more normal manner than livestock used to different conditions.

Selection of animals then depends specifically upon the objectives of the study, with proper recognition of the limits of application of the results and intelligent grouping of animals to reduce variation between lots.

ANIMAL MEASUREMENTS

Animal gains are most often used to measure animal response, and are usually expressed as either gain per animal per day or season, gain per acre, or a combination of these.

Hinman (1937) believes that the measurements of live-weight gains on animals is the most accurate and accessible means of evaluating pasture improvement. Mott and Lucas (1952) state that animal days and product per acre are very dependent upon factors such as type and physiological condition of the animal and their interaction with intensity of grazing.

Methods of weighing animals to determine weight gains have been subjected to careful scrutiny in the past. Baker et al. (1947) have shown that there was no advantage in taking animal weights on 3 successive days over the single weight when animals were subjected to uniform weighing conditions. These observations were confirmed by Hodgson and Knott (1942), Koch et al. (1958), and others. Patterson (1947) concludes that "data from 11 animals with single day weights would be expected to be slightly more efficient than those from 10 animals with 3-day weights."

Hughes and Harker (1950) found that, in the early morning, animals behave similarly; later individual behavior became more divergent. Weighing 3 hours after sunrise resulted in the lowest day to day variation in weight with the exception of weighing after a night (16 hours) fast.

Baker and Guilbert (1942) show that there is a nonrandomness in the variations of animal weights. A cyclic variation related to environmental factors (principally temperature) seems to exist. When animals were without feed and water during the night, the environmental influences were greatly reduced. These authors concluded that greater accuracy resulted from using more animals than more weights per animal. Bean (1948) concluded that weighing lambs for 3 consecutive days did not result in increased accuracy, and therefore there was no justification

for weighing an experimental animal on 3 consecutive days. Green et al. (1952) has found that live-weight increase curves based on fasted weights are smoother than curves from full weights.

Schalk and Amadon (1928), in referring to shrunk weights of animals, state that "the deleterious effect of fasting especially withholding of water may take many days to overcome." At the Central Plains Experimental Range in northern Colorado, several groups of heifers showed an average overnight loss in weight of 51 pounds, but in 1 day this weight had been regained plus an additional 5 pounds (Johnson 1944). Although young animals and mature dry animals can be shrunk overnight without harmful results, this procedure should not be used on lactating animals or their suckling offspring without further investigation of its effect on the animal.

Animal gain per day is primarily useful to evaluate forage quality, but does reflect to some extent quantity of forage also. Comparisons of different types of feed, such as reseeded ranges of different species, could appropriately be evaluated by gain per animal per day. Seasonal gain per animal can best be used to evaluate a grazing intensity experiment or a study of management methods. This measure tends to combine the response of the animal to change of habitat and to quantity of feed available. Gain per acre can best be used to evaluate productivity of grazing lands when grazed under similar conditions.

Klipple and Costello (1960) have shown that grazing intensity effects are often reflected in the condition and therefore market value of the animals. Whenever animal gains are used to evaluate a grazing treatment, these responses should, if possible, be interpreted in terms of market value. Johnson (1953) and Klipple and Bement (1961) have shown very clearly that market-value interpretations are of great importance when animal response is evaluated in terms of gain in weight.

Covariance analysis is useful to adjust for initial variability when there is reason to believe such variability influences the outcome of an experiment. When properly used, covariance will reduce variation in weight gain data of animals and can result in fewer animals being needed for grazing studies. Pechanec (1941) used this tool effectively for adjusting data of lamb weights at the end of the spring grazing season for variation in birth weight and age. In this case, covariance analysis indicated that the number of animals needed in specific grazing studies could be reduced by over 50 percent.

When breeding animals are used as the animal component of a study, other measurements of animal response become available. The number of offspring per dam over a given period, total weight of offspring per dam, productive life of the dam, mature weight of dams, and salvage value of the dam are all valid and useful measures of a grazing treatment. These productivity measurements are especially useful in studies of long duration (at least one generation of the animal). Both quality and quantity values of forage are reflected in these measurements.

GENERAL RECOMMENDATIONS

Grazing animals are sometimes used as a harvesting agent only, and as such there is little interest in the response of the animal itself. In most studies, the response of the animal to a grazing treatment is an important item of evaluation and controlled pastures are needed. General recommendations regarding use of animals are as follows:

1. For studies of such problems as grazing intensity (proper use) or methods of management on seasonal ranges where animal response is an important factor of evaluation, then;

a. Yearling steers should be preferred for cattle ranges, and, on the basis of present information, lambs running with ewes should be preferred for sheep ranges unless yearlings ewes or wethers are available and variability of gains can be determined.

b. Animals of the breed most common in the study area should be used if commensurate with the objectives of the study.

c. Small animals, such as rabbits, should be considered for pilot studies of either utilization effects or nutritive evaluations.

2. The breeding herd unit should be used for studies that require grazing throughout the year and involve productivity from different management systems or comparative evaluation of range forage types.

3. If animal response is sufficiently important to be measured, adequate numbers of animals should be provided to meet desired standards of precision. The 10-percent level of probability is recommended for this standard.

4. To minimize the magnitude of sampling problems, animals should be selected for (a) uniformity in size, age, breeding, management, and quality, and (b) vigor and health.

5. For seasonal studies of grazing effect on vegetation or of management methods, animal response should be measured in terms of seasonal gain, condition, and economic values.

6. For seasonal studies of nutritive values of range forages, such as a comparison of reseeded species, animal response should be measured in terms of daily gain or gain per acre.

7. For studies of yearlong grazing effects on vegetation or methods of management for yearlong ranges where breeding herd units are involved, animal response should be measured in terms of:

a. Percent offspring crop at weaning.

b. Weight and gain of dam and offspring.

c. Salvage value of dam and market value of offspring.

d. Percent death loss.

e. Productive life of the female.

8. For nonlactating animals, weights should be obtained after an overnight shrink.

9. For lactating animals and their sucking offspring, number of animals should be increased about 10 percent, and one weight obtained during early morning.

10. In assigning animals to pasture studies, animals should be grouped into homogeneous units that are allotted across all pastures on all treatments.

ESTIMATING GRAZING VALUES FOR LAYOUT AND CALIBRATION OF EXPERIMENTAL RANGES

Merton J. Reed and Jon M. Skovlin [1]

Our purpose is to evaluate the methods by which range units needed for a grazing study can best be established on a specific piece of land. Recognizing the impossibility of obtaining perfection in establishing units, how can this limitation be compensated for? As the study begins and continues, what methods can be used to determine necessary or desired adjustments in stocking to meet fluctuating herbage crops or related conditions?

Almost always, experimental range units are planned to satisfy, as nearly as possible, certain desired requirements. They may be of planned equal or unequal capabilities and must support the desired number of animals. More important, they must insure that—within reasonable limits—the level or levels of grazing applied will be those desired. Similarly, they must insure, so far as possible, that changes in range unit grazing values and livestock performance are due to planned treatments and not to original, unplanned differences in grazing value. Consequently, in this context, grazing value includes both quality and quantity of the available forage.

There are limits to the amount of effort that should go into laying out rangeland units of planned grazing values and in indexing such values:

First, the principal value of such information is to aid stocking during the treatment phase. Pretreatment values at the range unit level have a secondary use as possible covariants in making a more critical analysis of treatment effects. But, treatment evaluation at the range unit level, while of use for gross purposes, has limited value for extending research results on heterogeneous range types (Reppert, Reed, and Zusman 1962).

Second, the concept of equal range units and acceptable replication comes into question. Much of the accumulating experience from grassland research, including that on improved pastures, supports this. Further, when experimental treatments are based on planned levels of herbage removal by grazing, replication is often confounded because of the difficulty in physically attaining reasonably similar levels of use.

Third, precision in equalizing among units, either in establishment or in treatment application, need not be refined beyond the level of reliability or bias in sampling and measurement techniques. For each experiment, there is some point where these lines of refinement coincide.

Sampling accuracy applies equally to the pretreatment and treatment phases of research. The success realized in laying out and indexing the caliber of experimental units and in adjusting stocking will be only as good as the accuracy of sampling carried out—both in space and in time.

STATUS OF KNOWLEDGE

In 1939, Pechanec and Crafts (Crafts 1939; Pechanec 1939) reported on methods of measuring range grazing values. What they said then still holds true today.

Range or pasture researchers and land managers have used relatively few methods or approaches for estimating grazing values. Problems in estimating were recognized early and methods developed. Through the years some methods have been discarded and others have persisted. Specific information on alternative methods and their worth is conspicuous by its scarcity.

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[1] This paper is based on published material and the experiences of a number of Forest Service research personnel working on widely different range types in the West. The authors especially acknowledge the contributions of Don A. Duncan, S. Clark Martin, E. H. Reid, H. W. Springfield, and George T. Turner.

Progress in this field has come in refining knowledge and in appreciation of the nature and characteristics of rangelands and livestock, their variability and its importance, and of factors causing or affecting these variations. Accompanying this has come refinement in experimental and sampling designs better adapted to assessing these variations.

LAYOUT OF UNITS

The principal interest in evaluating range unit capabilities for setting up units of known relationships lies in the so-called normal, modal, or usual relations. This approach gives an estimate of the number of stock that can be carried in most years. Some adjustment of this number or in length of grazing season may be made in some or all years; such changes depend on the weather-years experienced and the degree of precision to which it is desired to have the range grazed.

Unit Size

Two considerations, often slighted, bear on the size of experimental units: (a) An adequate size to accommodate enough animals per unit to permit normal behavior patterns; and (b) adequate size for the particular range type to provide a menu for the stock rather than a forced diet.

Little specific information is available, but adequacy of size of an experimental unit is materially more important as a research consideration on natural than on seeded range, and especially than on improved pastures. Wildness of livestock, particularly cattle, influences behavior under experimental confinement. There may be some animal-psychology limit of gregariousness to the minimum number of animals that can be run in one group. This possibility applies especially to range-reared stock. The proximity of range units and the age class of animals may be influencing factors.

Providing for selectivity in grazing is particularly important in most facets of research on natural range. Livestock and range responses under usual conditions are often a product of free-choice grazing rather than forced grazing.

Classifying the Experimental Units

We have indicated a concern with the usual relations among units. This requires that those range characteristics that are most stable in their effects on grazing values and that materially affect such values be delineated and mapped. Mapping should be to narrow limits, of one-half acre or less, depending on the importance of the feature and the approximate size of the planned unit. All available information about the range type and the specific range concerned should be used in identifying features to be included.

Aerial photographs.—To locate and map physical features, good aerial photographs of recent vintage are invaluable. The possibilities of photo interpretation for range purposes have as yet been little investigated. However, photographs can delineate shrub, grassland, and woodland. Photographs taken at certain stages of grassland maturity also hold promise for delineating plant communities and associated sites. Examples include dry and wet meadows on mountain ranges in the Pacific Northwest and principal communities of the northern Great Plains and of California annual-plant ranges.

Nonusable range.—Nongrazable land for a particular kind of stock is excluded in assessing grazing values. On mountainous range, such land includes areas of rock outcrops, steep bluffs and precipitous slopes, and dense timber that discourages palatable understory growth or animal passage. These or similar items occur on most ranges. For research purposes, subjective judgment should not be made of usable or nonusable areas based on preconceived ideas of stock habits under a proper level of grazing. Such decisions may or may not coincide with those of the grazing animal, particularly at heavier levels of use and in dry years. It is preferable to delineate and map such areas initially to help understand later research results.

Within usable range, the factor of unavailable space for plant growth because of sizable rocks, slash, down logs, access roads, etc., should also be considered. In a similar category is availability of herbage growing in and around shrubs, logs, cacti, and other obstructions. At a later stage, specific values for the various areas or average values for the type would probably be determined and excluded from the range unit grazing values.

Surface acre.—Even when nongrazable acreages are excluded, the surface acre is generally inadequate as a criterion for subdividing the range into units. Reasonably, the more homogeneous the range, the greater is the effect of acreages included within units on grazing capabilities of the units and the more applicable this criterion becomes. However, even researchers working with improved pasture do not find the surface acre entirely satisfactory for this purpose (Blaser et al. 1960). As with increasing homogeneity of ranges, surface acre allowances also tend to be more closely correlated with heavier than lighter rates of stocking (Riewe 1961).

Sites and vegetation communities.—On all range types, factors of site profoundly and constantly influence range grazing values through plant speciation, plant numbers, time of devel-

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opment, vigor of growth, and time of curing. Included are factors of soil, topography, climate, and organisms affecting the plant or plant community. Coinciding with material changes in site are material changes in plant communities. Generally, these features are conveniently mapped at the same time. Where soil-site relations have been developed, delineation by soil-vegetation associations is desirable. Within plant communities and sites, material differences in range condition also are mapped. As a minimum for a particular range, the principal factors in these categories should be identified and delineated.

Tentative Layout of Units

Information from the many range types shows that the influences of site, vegetation subtype, and range condition classes are major sources of variation affecting range grazing values. Consequently, at this stage, range units may be tentatively planned on the maps. Planned equal or unequal proportions of the several variables are included in the several units. Practical considerations, such as occurrence of sites, fencing requirements, and water development opportunities, nearly always limit perfection in attaining this goal.

Estimating Grazing Values

Information from similar ranges is always necessary in estimating grazing values. Rarely, however, is such information available by sites, vegetation subtypes, or range condition classes. Present knowledge of forage acceptability for many range species is incomplete. Similarly, information on the nutrient value of most species is fragmentary and meager. Estimates of grazing capabilities from similar ranges may be subjectively modified by comparisons between the sample ranges and the study range.

Comprehensive sampling of vegetation at this stage permits refining capability estimates and making adjustments among the proposed units. If properly carried out, this effort also provides a base record of the pretreatment characteristics of the vegetation for future comparisons. As a minimum, all or most of the principal forage species should be included. Care should be taken not to arbitrarily exclude plants or specific areas as unimportant without good evidence.

The practical aspects of sampling show which known and possible variables can or cannot be eliminated from consideration. If planned covariance can isolate variables within anticipated sampling limits, these secondary sources of variation may be tested throughout the range of occurrence. This provides added refinement in analyzing the effects of main treatments and additional information on treatment interactions.

When available from closely similar range, long-term information on usual relations of palatable herbage yields or grazing capacities of sites, vegetation subtypes, and condition classes generally is preferred to short-term estimates from the study range units. Refinement in application of such approximate information often is possible by comparing such vegetation characteristics as speciation, living root-crown area, and the like.

Foliage cover or foliage density.—Estimates of aerial plant parts used with preestimated proper use or palatability factors, as employed in the earlier reconnaissance and square-foot density methods, have generally proved poorly correlated with range grazing capabilities. Carefully applied, this method may adequately define relations among units. But it is doubtful that this value justifies its use compared with other methods.

Basal area and basal composition.—Range workers have made little use of these relatively weather-stable plant characteristics to estimate range-unit productivity relations of perennial plant ranges. Investigations along this line, however, may be worthwhile. Estimates of basal cover of forage species proved valuable in a grazing trial on Plains range near Miles City, Mont. When estimates were used as a covariant-index of pretreatment productivity per acre, post-treatment results were more critically and reasonably interpreted (Reed and Peterson 1961).

Palatable herbage yields.—Estimates of yields are currently favored as indirect measures of range grazing capabilities based on the vegetation. Particularly pertinent is the length of record, or the variety or normalcy of the weather during years in which sampling is carried out. Generally, more than a single year's record is necessary because of the different influences of different weather patterns on sites or vegetation subtypes.

Herbage yields are usually sampled at only one point in the seasonal development of the forage plants. Livestock, on the other hand, graze many ranges throughout most of the differential stages of growth of a number of palatable plants. Consequently, to estimate grazing values on ranges that are to be grazed while herbage is growing, at least two samplings during the growing season are recommended (Pechanec 1939).

Nutrient analysis.—Relative evaluation of part or all of the common herbage plants is practical and may aid range unit adjustment or sampling. For example, distribution of elk sedge (*Carex geyeri*) on the Starkey Experimental Range in eastern Oregon helped explain part of the variation in summer cattle gains. Gains were inconsistently related to levels of grazing on the several units. Analysis of principal plants showed

elk sedge to be of exceptionally high nutrient content and highly palatable during the late summer months when other herbage was mainly cured. A check on the proportion of this species among units showed that its presence was associated with some of the variation in cattle performance.

CALIBRATION THROUGH GRAZING

Adequate experience is lacking for critically evaluating calibration grazing as a general procedure for assessing pretreatment grazing values of experimental range units. Calibration grazing in range research is a fairly recent innovation. Reasonably, it appears a logical refinement. "Basic Problems and Techniques in Range Research" (National Academy of Sciences—National Research Council, 1962) discusses its use. Calibrating experimental units for a minimum of 3 years is recommended, if weather is about normal. But, until more information is collected, the efficiency of employing this additional preliminary step is open to question.

Apparent Aspects

Results are strongly influenced by the weather-years experienced. Deviations from usual grazing capacities and quality may occur, as well as interactions in the relations among units. These circumstances vary among range types, especially between annual and perennial plant ranges. Usually, large differences among units probably are adequately assessed by a 2- to 3-year trial unless unusual weather conditions interfere. A preliminary check also is provided on basic stocking capacities of the units. Further, if breeding animals are used during the experimental phase, a pretreatment estimate of their individual performance is possible. This information may be used to advantage for establishing balanced treatment groups (Ivens et al. 1958; Lynd et al. 1957; Mott and Lucas 1952) and as covariants in later analysis.

Grazing for calibration purposes requires that the same kind and preferably the same class of stock be used as planned for the experiment. Range units are grazed during the same season as that planned for the study, and all areas are grazed at the same time. All units must be grazed to a comparable degree. Usually this is to a level that is considered full use, or moderate use, under good management.

Accomplishing comparable use among units is difficult and time-consuming. This is especially true for heterogeneous and relatively large range units. Frequent herbage utilization checks, starting early in the season, combined with put-and-take adjustments in animal numbers probably is the most accurate procedure (Blaser et al. 1960; Mott and Lucas 1952). Unused palatable herbage late in the season that could have been properly used earlier while green and nutritious is forage quantity and quality that are not measured.

Use of only one or two key species in judging range use for this purpose is likely to be misleading. All or most of the principal forage species should be considered. For example, on mountain range in eastern Oregon a weighted-use figure of eight principal species (based on herbage yield and the use of each species) provided the most accurate picture of range grazing intensity.

Improvement in Design

The animal contribution to error in such trials is inverse to the number of animals grazed on a unit (Peterson and Lucas 1960). A design for calibration grazing developed for the San Joaquin Experimental Range in central California took advantage of this relationship. Balanced groups of heifers were rotated on a restricted random basis through the several units at 28-day intervals. In this way, the number of individual animals grazed on each unit during the season was increased. Rotating groups also facilitated pretreatment calibration of individual heifers.

A complete rotation of all groups through all units made possible an estimate of range unit effects on seasonal live-weight gain independent of confusion with heifer groups. Even incom-

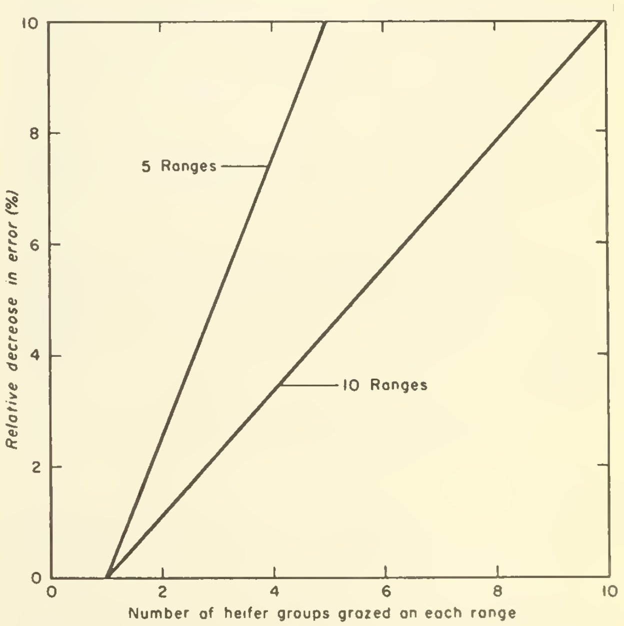

Figure 1.—Decrease in error of estimating range unit effect on heifer gain in relation to the number of heifer groups grazed on each unit, San Joaquin Experimental Range, 1960.

plete rotation helped reduce the error of estimate of range unit effects in comparison with no rotation. Under conditions at the San Joaquin Experimental Range, the relative decrease in error progressed to about 10 percent with complete rotation.

Expression of Results

Results are most meaningful when expressed in terms of animal products, e.g., live-weight gains, or in terms of total digestible nutrients (TDN) provided by the forage. The latter is presently favored in the United States in assessing improved pastures (Mott and Lucas 1952; Peterson and Lucas 1960; Pigden and Greenshields 1960). Computations are based on body weight of the animals; net gains made over the period; and the total digestible nutrients required for maintenance and gain of such animals, as derived from feeding standards. This type of expression has certain advantages. If mixed classes or kinds of stock are used, it provides a means for equating results to a common base. A limitation in this connection, particularly for rangeland application, is the requirement that the animals select the same kind of herbage. Further, if supplements have been fed, the expression permits subtraction of nutrients from this source.

The use of approximate feed requirements and calculation of TDN provided, however, appear unnecessary when the following conditions are satisfied:

1. The primary purpose of the trial is to estimate relative grazing values among a given set of units.
2. The units are grazed by fairly uniform animals.
3. Supplements are not provided; if they are, they are fed in limited amounts and all groups are fed equally.

A mathematical model similar to the one used in analysis of variance was developed for successfully partitioning heifer gains in the San Joaquin Experimental Range calibration trial described above. This model was expressed in the following equation.

$$G_{hrm}=P_{grm}+H_i+R_e+M_e+I_{rxm}+E$$

in which:

G_{hrm}=gain of a heifer on any range unit in any month,
P_{grm}=mean population gain of all heifers on all ranges in all months,
H_i=the heifer's individual ability to gain more or less than the population mean,
R_e=effect of the range unit on gains,
M_e=effect of the month or forage condition on gains,
I_{rxm}=interaction of range x month,
E=normally and independently distributed random error with mean of zero and variance σ^2.

For analyzing several years' data, year effect and year interactions are included in the model.

USE OF RANGE UNIT INDEXES

All the foregoing criteria provide indexes of the relations among range units. If wide discrepancies from planned relations exist, range unit fences can be adjusted. Under most circumstances, neither fences nor any class of vegetation should be deliberately modified. Generally, it is better to live with measured differences than with unmeasured ones.

Some or all the foregoing indexes may serve as valuable covariants in analyzing later treatment response in livestock or range unit performance. All should be tested for this purpose.

ADJUSTMENTS IN STOCKING

Study designs often provide for adjustments in stocking during calibration and treatment phases. These may be between years, within years, or both, to compensate for changes in forage availability. There is less information on objective methods for accomplishing this task than for any other aspect of range management because of the many variables involved.

The task is materially easier if herbage is fully grown or a majority of growth is completed before adjustments. For example, plant growth is completed on the semidesert grass-shrub range in Arizona before stocking adjustments are made in early November. Similar conditions occur on California annual-plant ranges grazed during the dry forage season and on some mountain ranges used for summer grazing.

When forage production can be predicted or determined by sampling, desired stocking can be computed from predetermined or preestimated dry-matter requirements per animal. Such animal-requirement factors must be developed from experience and closely adapted to the range concerned.

Use of the interrelations of palatable herbage production, stocking, and herbage use shows promise for estimating desired stocking on several experiments on natural and seeded range in Arizona, Colorado, and New Mexico. Past records are used to develop a multiple regression equation among these variables. Allowable

stocking can be computed when current palatable herbage production and the desired level of use are included in the equation.

For perennial grass ranges, the equation in generalized form is as follows:

$$U=a+b_1\frac{1}{P}+b_2\frac{1}{S}$$

in which:

U=herbage utilization in percent by weight,
P=production of principal forage grass or grasses in pounds per acre,
S=stocking rate in acres per animal-unit month,
a, b_1, and b_2=constants derived by regression analysis of past data.

In experiments in which crested wheatgrass was the major forage producer, multiple correlation coefficients of 0.97 or higher have shown that such equations are good tools for making stocking estimates. Correlation coefficients of 0.92 or higher also were found on black grama range and on mountain grasslands where perennial grasses were the principal forage species.

The following equation [2] has proved useful for the semidesert grass-shrub range on the Santa Rita Experimental Range in Arizona where annual grasses and shrubs are important sources of forage as well as perennial grasses.

$$\frac{1}{U}=a+b_1\times\frac{P_a}{S}+b_2\times\frac{P_p}{S}$$

in which:

P_a=production of annual grasses in pounds per acre,
P_p=production of perennial grasses in pounds per acre.

The other symbols are similar to those used before.

High correlations between these factors and a high level of comparability between estimated and actual use were found (table 1).

Separate regression equations are usually necessary for each range unit. Best relations have been found in areas having perennial grasses as the principal forage. Poorest relations have resulted where shrubs and annual grasses are important forages, because production and use of these plants are difficult to measure.

[2] Martin, S. Clark. Obtaining prescribed utilization in grazing studies by using records of herbage production, stocking and utilization. (n.d.) (Unpub. rpt. on file Rocky Mountain Forest and Range Expt. Sta., Fort Collins, Colo.)

TABLE 1.—*Relation between estimated and actual use on one range unit, based on derived regression among use, palatable herbage production, and stocking, Santa Rita Experimental Range, 1955–61* [1]

Year	Estimated use	Actual use
	Percent	*Percent*
1955	68	63
1956	50	56
1957	81	70
1959	31	30
1960	27	27
1961	53	59

[1] Regression coefficient (R)=0.9846; R^2=0.9694.

Stocking, which is being estimated, is an independent variable in the regression equation. This must be recognized when making the estimate and determining confidence limits.

Soil moisture or precipitation data for particular times may help predict palatable herbage yields in certain range types (Dahl 1962; Sneva and Hyder 1962). This possibility depends on the climatic pattern and varies within areas with soil depth and water storage capacity. These relations, however, should be investigated on most range types. For specific range units, correlations of yields with those on fixed, limited sampling areas may have merit for estimating relative, annual changes by reducing sampling effort.

On many ranges, rainfall during the current growing season largely determines the herbage crop produced. Stocking often continues from some early stage of growth to maturity or later. Not infrequently, part of the current crop is reserved for part or all of the nongrowing season. In such cases, stocking adjustments between years and within season depend mostly on sound judgment. Frequent use checks and familiarity with the range and weather influences form the best and only reasonable method in these circumstances.

Quantitative information on the relations between range condition and trend and stocking is meager. In the usual sense, range condition and trend result from grazing use and changes in trend are measured over a period of time. These range criteria, however, combine the various influences of grazing into one or several meaningful expressions. Because of their nature, these criteria generally are best adapted to judging relatively long-term adjustments in stocking. Certain sensitive criteria of range trend may be adapted to judging the effects of the preceding year's stocking. These include normalcy of height growth or other vigor expressions of prin-

cipal forage plants commensurate with weather and, possibly, soil-surface litter cover on semiarid western ranges.

RECOMMENDATIONS

Review of available information makes clear two principal needs. First, attention should again be promptly directed to evaluating criteria and methods for quantitatively estimating grazing values, both stocking capacity and palatable herbage quality, for major range types. Continued improvement is critically needed in both research and land management. Second, data should be collected and made available as rapidly as possible for critically evaluating the worth of calibration grazing as a research approach in range grazing studies.

Based on present knowledge, we recommend the following steps:

1. Develop precise and accurate maps (aerial photographs) and acreage determination on the specific range area of grazable and nongrazable range, meaningful sites, plant communities, and range condition classes.
2. Use all available information on forage productivity of sites, plant communities, and condition classes in establishing experimental range unit boundaries, site composition of units, etc.
3. Carry out pretreatment calibration grazing for 2 or more years, with the same animals or similar animals to be used in the experiment.
4. Conduct annual, seasonal, or within-season utilization surveys during calibration and the experiment to make stocking adjustments, if part of the design, and to help adequately define and describe the treatments applied.
5. Test the value and use of data in 2 and 3 above as covariants for more critically evaluating experimental results.

SOME STATISTICAL PROBLEMS IN DESIGN AND CONDUCT OF GRAZING EXPERIMENTS

Jacob L. Kovner

PRACTICAL LIMITATIONS IN FIELD TRIALS

There are statistical methods and designs that can be of some help in these circumstances. In the design and conduct of grazing experiments, the use of animals as a treatment imposes certain practical limitations. For example, an experimental unit must be large enough to support at least one animal for the duration of the grazing period, and it should include areas that are representative of the vegetation complex being studied. Furthermore, to typify the pattern of grazing and animal response of the herd, use of relatively large numbers of animals per plot is necessary. This results in a plot size on native ranges that may be 1,000 acres or larger, with 300 to 400 acres not unusual. The blocks have corresponding dimensions. This characteristic of grazing experiments introduces notable departures from the usual concepts of experimental design, which should provide for adequate control of variability.

Some control of the experimental variability may be achieved by proper choice of design. Generally, a design becomes more complex as variability increases. In grazing experiments, this approach has its limitations and it may be said that the simple designs suffice. Randomized complete block designs are used almost without exception. In some cases, the split-block arrangement of treatments; which falls in the category of incomplete designs, should be employed. This appears desirable where it is more economical to impose the grazing intensity treatments over large areas with subdivision for another group of treatments.

Another method of obtaining adequate control of variability is to increase replication. In any experiment, initial planning should establish the number of replications necessary to obtain the desired precision. Hilmon et al. (conference paper) have presented a table for estimating the number of range units per treatment necessary to obtain the precision stated. Their table is adequate for range work. If the required replication is not possible, the general recommendation is not to do the experiment.

The table indicates that, with a coefficient of variability of 20 percent (which is probably not unusual) and a difference of 20 percent of the mean to be demonstrated, 17 replications are needed. If standards are relaxed to accept a difference of 40 percent of the mean, 5 replications are still needed. Higher coefficients of variability increase the number of replications rapidly. To find suitable range areas large enough to accommodate the last figure is not easy. In addition, costs of fencing, water, stocking, and taking records impose additional dif-

ficulties. With three rates of grazing, two or three replications are usually used for native ranges, and possibly three or four for seeded pastures. This would suggest that the differences to be demonstrated will have to exceed 40 percent of the mean.

Grazing treatments are not restricted to intensity of use, but may include, for example, cultural practices, season of use, range rotation, and deferred grazing. In comparing plant and animal responses to a set of treatments, it is often desirable in addition to determine the point or range of optimum stocking or use (Mott 1960) and possible interaction of the two factors. Whatever the design, the treatment combinations increase rapidly, and a replicate will require a large number of experimental units. For example, three seasons of use treatments and three levels of grazing intensity amount to nine units per replicate. Four to five replicates or 36 to 45 units would still be required to demonstrate a difference of 40 percent of the mean, with a 20-percent coefficient of variation and probability levels, as stated in Hilmon's table.

In grazing experiments, particularly when vegetation responses are involved, it is necessary to resort to sampling in lieu of a complete inventory of the experimental units. Sampling results in a loss of information compared to complete measurement, since the sampling variability is added to the inherent plot variability and thus inflates the experimental error for a given response.

Hilmon et al. (conference paper) give an application of the theory developed by Yates and Zacopany (1935) for determining the optimum sampling rate for a fixed quantity of information which is defined by them as

$$Q(1-L)=1$$

where $Q=r/r_o$, r_o is the number of replicates in the standard experiment with complete harvesting, and L is the loss in information. Now r_o is estimated initially from tables, as mentioned earlier. Upward adjustments in replication will depend, therefore, on the sampling variance and the rate of sampling. This also raises a problem, since in the course of a grazing experiment, the sampling variance may increase due to treatment and seasonal (year) effects. Sampling rate should then be adjusted accordingly, or the whole experiment may be rendered inadequate, since it obviously will not be possible to change the number of replications once the experiment has begun.

The above suggests that range experimental units should be reduced in size so that a larger number of replications may be accommodated on available areas. With smaller relatively homogeneous areas, the coefficient of variation will be decreased, and fewer replications will be needed for a given precision. Also, the sampling rate will tend to be more commensurate with available resources. Very likely experimental units may be reduced in size, at least to the extent that smaller prototype experiments can be used to screen a large number of possible treatments. The full-scale experiments may then be employed to compare selected important treatments on a field trial basis. Lucas (conference paper) is of the opinion that "by thinking of factors involved in the system one can imagine many sorts of critical experiments regarding sward behavior that can be done with small plots using the animal as a treatment tool."

REFINEMENTS IN ANALYTICAL METHODS

There are statistical methods and designs that can be of some help in these circumstances. Often some of the experiments will be repeated at different places and at different times to study the variation in treatment effects. The results of individual experiments can often be combined to obtain more accurate estimates of treatment effects, and the overall precision for testing differences can be improved by increasing the degrees of freedom and obtaining better estimates of the error variance.

Harlan (1958) has taken gain per head data from 14 separate intensity-of-grazing studies conducted all over the United States and developed a generalized curve that relates gain per head to stocking rate. Although the data were subjected to extensive, nonstatistical manipulation, considerably more information was obtained than could have been derived from the individual experiments. Quenouille (1953) has an extended discussion and summary of available techniques for combining results of more than one experiment. As is to be expected, the overall design and analysis should be specified in advance if the best use is to be made of these methods.

Another related aspect of the problem has to do with spacing of treatments in range studies. In view of the precision attainable, as indicated above, small differences between treatment effects will not be detected. For example, with intensity-of-use experiments, the treatments are generally of the order of light, moderate, and heavy rates of grazing. This is dictated to some extent by the fact that a given rate of use can only be achieved within, say, 10 percent use. Nevertheless, the same rule should be applied to other categories of treatments in the sense that, regarded as levels of a factor, the treatments should be widely spaced.

Riewe (1961) has recognized the replication problem and proposed an analysis for a two-factor experiment with one replication. At least one of the factors must be quantitative, so that regression comparisons of the other factor may be made. This situation obviously pertains to grazing experiments in which one of the factors is rate of grazing. The method makes use of the analysis of covariance for comparing regression equations from independent sets of data. Of course, experiments with one replication are generally not very satisfactory and are not recommended.

The difficulty in a two-factor layout with one replication is that there is no error term for testing interaction. Main effects can be tested only if it is assumed that no interaction exists, that is, the model is additive. With replication, no such problem exists. Of course, it has been suggested that in large factorial experiments third and higher order interaction mean squares be used as experimental error when there is information that they are not real. (See fractionally replicated experiments described in Cochran and Cox (1957).) While Riewe's (1961) method has merit, a better procedure for the factorial model is to partition the interaction sum of square into successive linear, quadratic, etc. effects, depending on number of treatments, and then use the residual sum of squares as the error sum of squares for interaction effects (table 1). This method can be used equally well when both factors are quantitative (Scheffé 1959).

TABLE 1.—*Riewe's data and analysis*

Stocking rate (number of animals per section)	Animal gains			
	Treatment A	Treatment B	Treatment C	Mean
	Pounds	*Pounds*	*Pounds*	*Pounds*
16	119. 0	193. 0	194. 0	168. 7
32	94. 0	156. 0	113. 0	121. 0
48	76. 2	109. 0	26. 2	70. 5
Mean	96. 4	152. 7	111. 1	
Analysis of variance:				
Source	DF	SS	MS	
Treatment (T)	2	5, 111. 62		
Stocking rate (S)	2	14, 468. 98		
TXS	4	4, 084. 27		
Linear	2	4, 057. 47	[1]2, 028.74	
Residual	2	26. 80	13. 40	

[1] Significant at the 1-percent probability level.

Note that the linear component is significant, which indicates the presence of interaction between stocking rate and treatment. The test for treatment means is, consequently, not of much interest. With no significant interaction the treatment mean square could be tested against the TXS mean square.

APPROPRIATE DESIGN INNOVATIONS

In experiments where the necessary replication can be attained, the general methods involving response surfaces may be very useful. Designs would be necessary that require a relatively large number of plots so that treatments are introduced in factorial combinations of different levels. Interaction terms can be included in the model. It is assumed that the levels of the factors, which are the independent variables in the regression model, are measured without error.

Range management, in certain applications, can be regarded as the manipulation of various factors in combination to produce optimum responses. This outcome may be visualized in experiments that deal with animal products. For example, we might want to find the combination of grazing intensity, amount of fertilizer, and distance between water facilities that results in maximum live-weight gain per acre. A problem of this kind, in which the factors are quantitative, may be handled statistically by the study of response surfaces. The idea is to express the particular response as a function of the levels of the factors, which are now regarded as continuous variables. If the function can be determined, it may then be possible to solve for the values of the variables that maximize the response.

Where plots are limited in number, the single-factor method described by Friedman and Savage (1947) can be employed to advantage. As applied to the above example, the fertilizer and water distribution would be held fixed at estimated optimum levels for the first trial. A minimum number of three levels of grazing intensity, but preferably four or five, covering the optimum response are compared. A quadratic equation is fitted to the data, if the maximum appears to exist, and the level of grazing intensity that produces maximum gain per acre is calculated. In the next trial, possibly on the same plots, the grazing intensity is fixed at the optimum level, the water distribution remains fixed, as before, and various levels of fertilizer application are introduced as treatments. These are compared in the same way and the optimum level determined. In the final trial, the water distributions are compared.

At the end of the first round, a set of optimum levels has been determined. Sometimes it may be necessary to begin another round. This method works best where factors are essentially independent. It is not very efficient, however, for range experiments because they usually extend over a long period of time.

OTHER DIFFICULTIES IN CONDUCTING RANGE EXPERIMENTS

The design of grazing experiments involve other factors that aggravate those associated with the lack of replication. For example, it is customary in field trials to group adjacent plots into homogeneous blocks. This does not necessarily work for range areas, since variability between adjacent areas is often as large as that between those some distance apart. In several actual cases, the block sum of squares contributed very little to reducing experimental error at the expense of reducing the degrees of freedom of the error mean square. Also, as mentioned earlier, prescribed rates of use or levels of grazing are very difficult to establish on plots, and planned replication may not be achieved with the result that treatment effects are not well defined and experimental error is inflated.

Reed and Skovlin (conference paper) have considered these and other problems and pointed out the necessity for finding methods for estimating the grazing values of range units. Such values could be used as a basis for delineating plots into blocks and fixing rates of grazing. Calibration in the form of pretreatment sampling of range variables and uniformity trials were suggested as solutions to these problems. Pechanec (1941) has shown how covariance analysis can be used with calibration data to increase precision of range experiments.

With reference to problems already mentioned, it should be noted that grazing studies are by nature long-term experiments that not infrequently have a duration of 10 years or more. This follows from the necessity to study the cumulative effect of a grazing treatment and the effect due to individual years or seasons on range condition. With techniques suggested by Reed and Skovlin (conference paper), preliminary estimates of the grazing value of range units could be obtained and the experiments initiated.

Some deviation from prescribed treatment levels could be tolerated in the early stages of the experiment without seriously affecting the final outcome. Also during this period, estimates of sampling variation can be obtained to determine the intensity of sampling required under actual conditions. Visible defects in design or conduct of the study can be repaired by making necessary adjustments. Treatment differences tend to become larger with time, a fact that has many obvious benefits. There is the precaution, however, that too many subjective decisions during the course of the experiment can shift the results in almost any direction.

REUSE OF EXPERIMENTAL AREAS

One problem that arises, without an overall solution, is what to do with areas after termination of an experiment. Since suitable range units are not easily found, and development costs are high, acquisition of areas for new experiments can be a major obstacle. The old units cannot be employed without introducing some interaction with carryover or residual effects. Presumably, these will disappear if enough time is permitted to elapse between experiments, or if cultural treatments are applied to bring the pastures back to some kind of homogeneity. This can be both time consuming and expensive.

An alternative is to use each plot of the original experiment as a block in the randomization of the treatments of a new experiment. This appears feasible for experiments without animals. Unless the original plots were very large, the problem of minimum size for grazing would be encountered, and the number of new treatments would have to be limited. This difficulty could be met by using incomplete block designs. Some advance planning would be needed, however, to accommodate the randomization restrictions of incomplete designs.

MULTIVARIATE ANALYSIS

Grazing experiments are generally conducted to study numerous responses to the treatments. Multiple measurements are taken on the experimental units, whether they are field plots or animal units. Examples include production of individual species on a plot, measurements of various physical and chemical characteristics of plants, animals, and soils, and measurements repeated in time. A multivariate analysis of variance (MANOVA) is suggested for this type of problem (Smith et al. 1962). Covariance or multiple regression analysis will not be appropriate since none of the responses, by definition, can be regarded as covariates in the sense of being independent of the treatment effect. Also, the responses as described above would tend to show high correlations.

The usual practice is to analyze each response variable separately and ignore any correlation that might exist between them. Steel (1955) has summarized the problem rather neatly:

> If such multiple observations are analyzed on the basis of separate variables, the combination of the results of univariate tests and the assignment of a measure of credibility to any inference drawn present problems. Thus if the observations are perfectly correlated, the same conclusions are drawn from each variable; if the observations are completely independent and it is agreed to claim a difference at the 5% level if at least one variable shows significance, then one falsely claims significance with a probability $1-(.95)^n$ with n variables; if the rule is to claim a difference only if all variables show significance, then the probability of falsely claiming a difference is $(.05)^n$ for n variables and it becomes practically impossible even to detect a difference. In either case, rules can be constructed and inferences made with valid measures of credibility, but the true situation is probably somewhere between complete dependence and complete independence and we simply do not know the level of significance. In a multivariate analysis the problem of dependence is looked after by the criterion itself.

The application of MANOVA to multiresponse experiments has been limited due to the very laborious computations required. The advent of high-speed computers has helped to overcome this difficulty, and in recent years several papers have appeared that show application of MANOVA to the kind of data that are obtained in range experiments.

Steel (1955) presents an example that applies to grazing experiments repeated in time, although data for only 2 years were taken. The usual treatment tests are made which eliminate the need for assuming homogeneity of variance. Also, the analysis leads to two independent discriminant functions for testing variety and variety-time interaction effects, which can be useful in making exact probability statements in comparing means. All the years of an extended experiment need not be included in such an analysis. It might be advantageous, however, to use the method for the last 3 or 4 years of an experiment when cumulative treatment effects might be worth testing subject to year-to-year variation.

Danford et al. (1960) consider the problem of testing treatment effects when some characteristic of the experimental units is measured repeatedly in time. Animal weights are taken in grazing experiments, although usually just at the beginning and end of the grazing period. It is not unlikely, however, that some studies would benefit from periodic measurements during this time. For the selected data, the authors show that the assumption of equal variances and covariances for the different times is violated, and the ordinary univariate analysis may not be valid. This would appear to be generally true for this kind of data, since measurements next to each other in time would show higher correlation than those well separated in time. In this particular example, essentially the same inferences are obtained by the univariate and multivariate analyses. Also, the authors point out that for very large samples the two analyses are asymptotically identical. Large samples are not generally obtained, however, in range experiments.

Smith et al. (1962) apply MANOVA to the problem of multiple responses on each unit. The example selected includes 4 treatments and 11 separate responses, among which a large number of highly significant, meaningful correlations are shown to exist. The treatments were originally compared by individual responses assumed to be independent and the resulting risk, in terms of probability, will be quite high. The paper does not compare the univariate and multivariate analyses but illustrates some of the computations and tests made with MANOVA.

It is noteworthy that the analysis can be used to determine a subset of the responses and still be able to differentiate between treatment groups. In grazing experiments, this technique might be valuable in finding a subset of species that will differentiate between treatments. The paper also points out that the computations are not too formidable with high-speed computers and, in fact, a program of analysis on the IBM 705 II has been developed.

SUMMARY

Because grazing experiments must be conducted on a scale commensurate with actual practices, the problems are many. Nonhomogeneity in treatments and experimental units and lack of climatic stability combine to rob experiments of desired precision. Some statistical methods for minimizing these difficulties are presented. The fact that grazing experiments are usually long-term studies offers an advantage. Multivariate analysis should be exploited.

COMMITTEE REPORT ON THE DESIGN AND CONDUCT OF GRAZING EXPERIMENTS

Grazing experiments, although expensive and time-consuming, are one of the best methods for developing and testing new knowledge essential for the wise use and management of rangelands. Such experiments should be as adequate and efficient as possible within the limits of available resources. Careful attention to statistical design, size and shape of experimental units, replication of grazing treatments, and sampling systems and techniques for determining treatment effects will implement these requirements. Recognition and usage, where possible, of the common practices of the local livestock industry are advisable.

The experimental design of any grazing study should be chosen only after the specific objectives of the undertaking have been thoroughly worked out. Selection of the design is contingent upon whether the primary objective is to determine response of the vegetation or the animals to the treatment applied. Generally, animals are utilized as the treatment mechanism in either case. Animal responses are often used to describe treatment outcome on large range areas, whereas individual small sites in the range units better reflect vegetation response. In some cases fencing and grazing by sites may have merit. Furthermore, differences between grazing treatments may not be as important, particularly in research, as changes within a treatment.

In the past, two or three treatment levels in simple randomized block designs have been used; this design prevented analysis for more than simple linear relationships. In the future, designs incorporating a wider range of treatments or an increased number of treatment levels should be considered. Such designs may provide more information on treatment effects despite the fact that the increased number of treatments may preclude replication of some or even all of the treatment levels.

Livestock used in grazing experiments should be uniform as to breed, class, age, weight, general vigor and health, and previous management history, and should be typical of those predominant in the industry locally. Yearling steers or ewes are suggested for seasonal studies, but breeding animals are preferred for studies of yearlong management procedures or productivity evaluations of livestock or range. Lambs and calves may not reflect a grazing treatment because of offspring-dam dependency. Moreover, a severe grazing treatment might affect breeding animals by causing a delay in the calving or lambing date.

Other available information, such as performance data, grading system evaluations, or genetic records, should be utilized in initially trying to balance the herds. Where calibration grazing is being used on experimental range units, actual performance of the animals should be recorded and utilized to further reduce variability between herds, either by physically modifying herd composition or by using a measure of herd performance as a covariate in the analysis. Adequate numbers of animals should be provided to meet the desired standards of precision in the experiment. Ten animals per lot or range unit are usually considered the minimum for statistical analysis (National Research Council 1962). The optimum number, however, varies with the type of study, range unit size, animal, and grazing season. For most range studies, it is recommended that enough animals be provided to obtain an estimate within 10 percent of the mean of the measured response at the 95-percent level of probability.

Inherent differences in experimental range units used in grazing studies make it difficult, if not impossible, to impose desired treatments without some adjustments before treatments are imposed. Comparability of the range units to be used in the study should be evaluated as fully as possible, and adjustments should be made in size of unit, number of animals, or duration of grazing to compensate for differences. Further tests of comparability or calibration using grazing animals may also be essential, but their value in different types of grazing studies as compared to their cost needs careful study. Where calibration using grazing animals is desirable, it should last 2 to 4 years.

Some modification of the planned experimental layout may be indicated upon completion of the calibration period. However, caution is suggested in making such changes to avoid introducing additional and unaccountable variation into the experiment.

The following statement, borrowed from "Research Techniques in Use at The Grassland Research Institute" (Hurley, England), effectively expresses the consensus of the committee in the use of statistics in grazing experiments:

> Whether it be a simple experiment or a complex piece of research, planning is an important (perhaps the most important) phase of the experiment. This demands much thought by the researcher; and it should also be thoroughly discussed with other colleagues, including those with a knowledge of statistical methods and experimental design. Having thoroughly discussed the trial with other colleagues during the planning stage, and noted their combined suggestions and comments, the experimentalist himself must then be responsible for the precise design and the ultimate execution of the experiment. This appears to be the sensible approach to the problem of design and procedure in any experiment. Too

often, however, the tendency among field workers (and among those in administrative control) is to demand that the statistician define and ultimately decide upon the precise design of experiments. The field worker, himself, should accept full responsibility for both the theoretical and practical execution of his experiments. Modern grassland research demands the knowledgeable use of biometrics, but it also demands accurate recording, subjective as well as objective, in order to compile a complete picture of range behavior all through the phases of growth and development.

RECOMMENDATIONS

Increased emphasis should be given to the development, application, and distribution of statistical designs and techniques that are appropriate for evaluating animal and plant responses in range management research. Such techniques as multivariate analysis and response surfaces should be explored more fully for this field of research. Adaptations of experimental designs that provide suitable means for coping with the type of physical plant with which the range researcher must contend are needed. Highly variable topography, soils, climate, vegetation, animals, and animal behavior complicate his problem.

Assembly of available planning factor data from previous range research is recommended. Related to this is the need for accumulating and making available, as rapidly as possible, information that is pertinent for critical evaluation of calibration grazing as an approach in grazing studies.

Criteria should be evaluated from quantitatively estimating grazing value (i.e., both stocking capacity and forage quality) for the major range types. Improvement in current procedures is critically needed for both research and land management.

There is need for development of an automatic recording scale for obtaining animal weights in grazing experiments. The scale would weigh the animals without the disturbance that is caused by moving them to conventional scales. Such a scale should identify an animal as well as weigh and record its weight during its normal pattern of movement.

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